Grounding Line Derivation Over Antarctic Ice Sheet from Sentinel-1, TerraSAR-X and ERS-1/2

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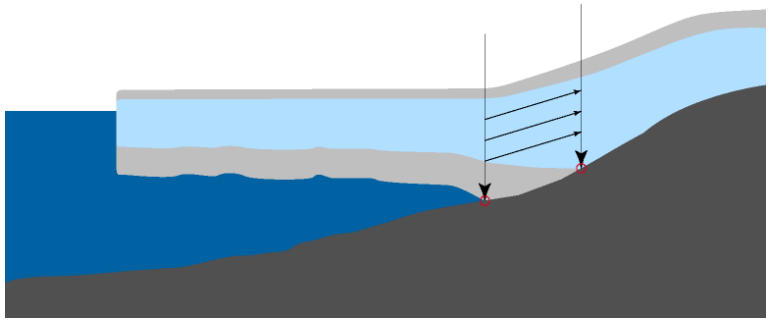
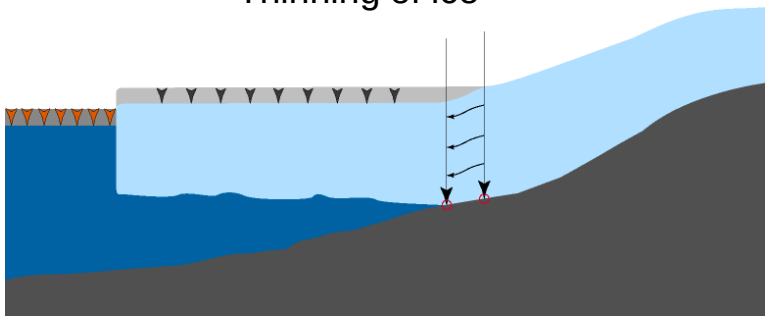
Motivation and Goals for GLL derivation

Motivation

- Grounding line locations (GLLs) need to be compared in order to reveal retreats caused by ice thinning
- None of the currently existing GLL database provide information on:
  - Ocean tide level
  - Air pressure



Thinning of ice

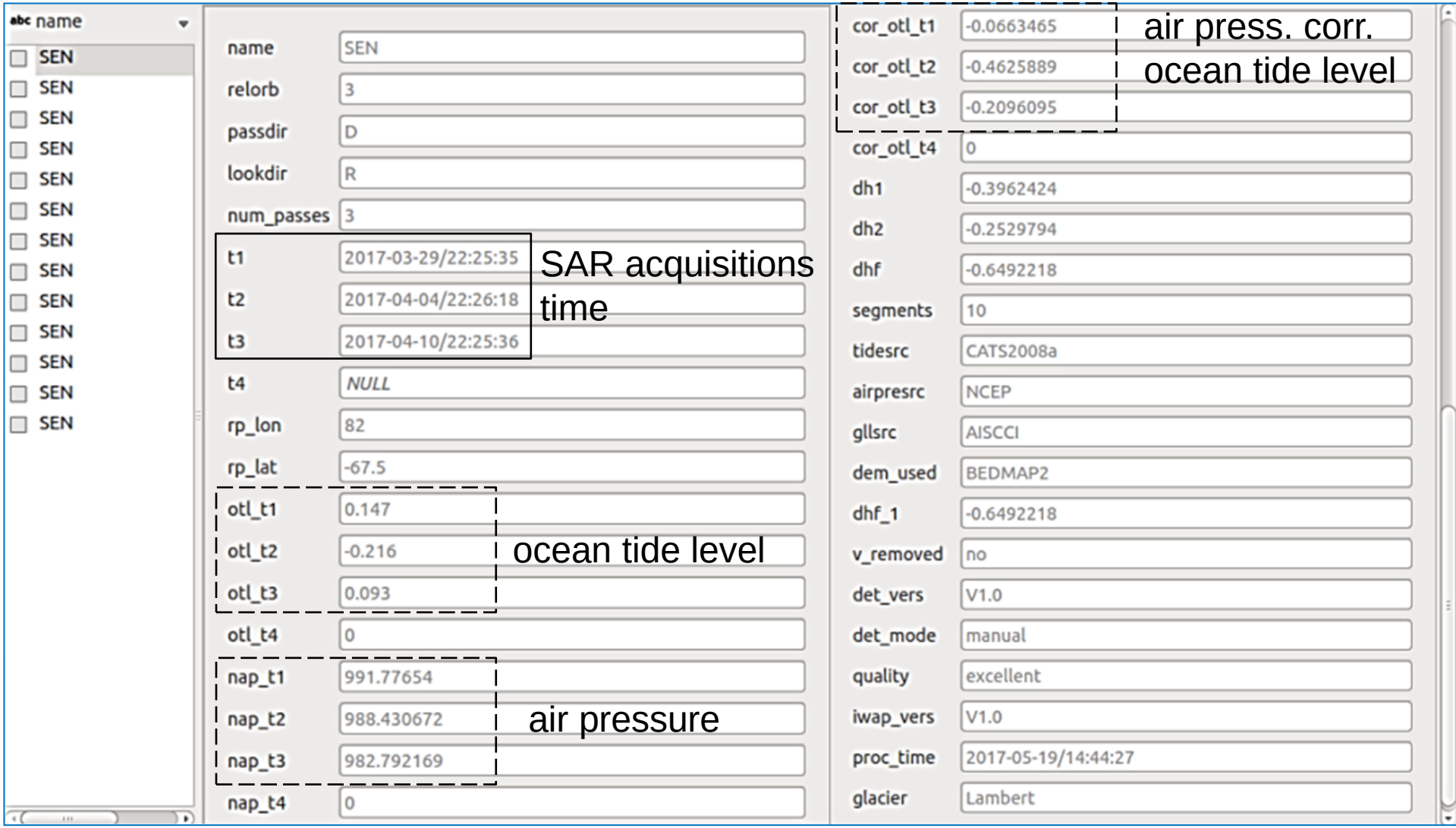


Ocean tide level
(also affected by air pressure)

Goals within Antarctic Ice Sheet climate change initiative (AIS_cci) project

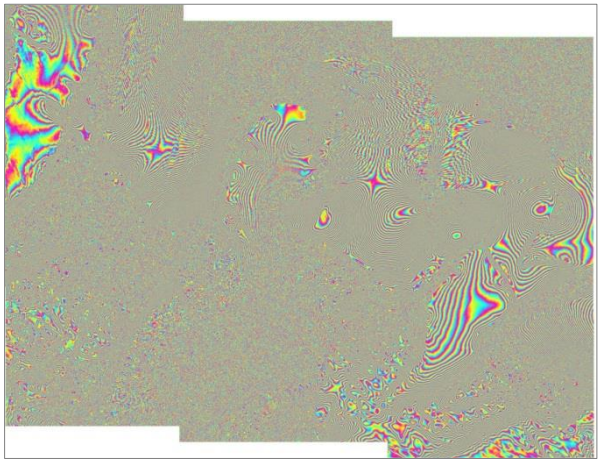
- Derive GLLs on key glaciers as precise as possible
- Generate time series of GLLs from ERS-1/2, Sentinel-1A/B and TerraSAR-X
- Provide GLL products with additional meta data

AIS_cci GLL products – metadata

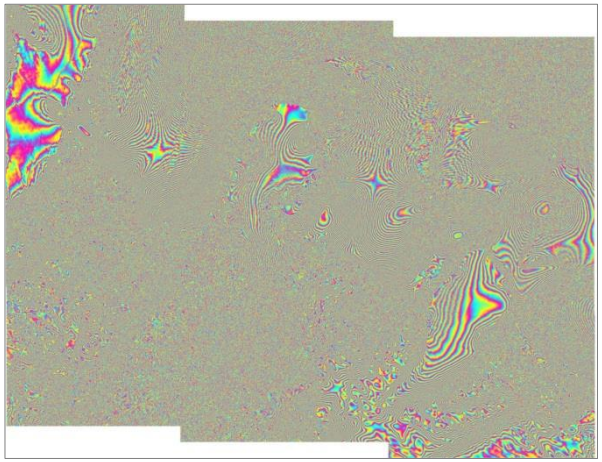


Methodology for GLL derivation - InSAR double differencing method

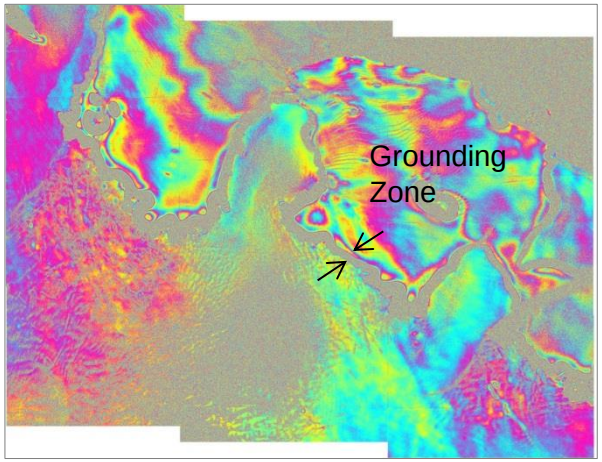
Interferogram (t_1 & t_2)



Interferogram (t_2 & t_3)



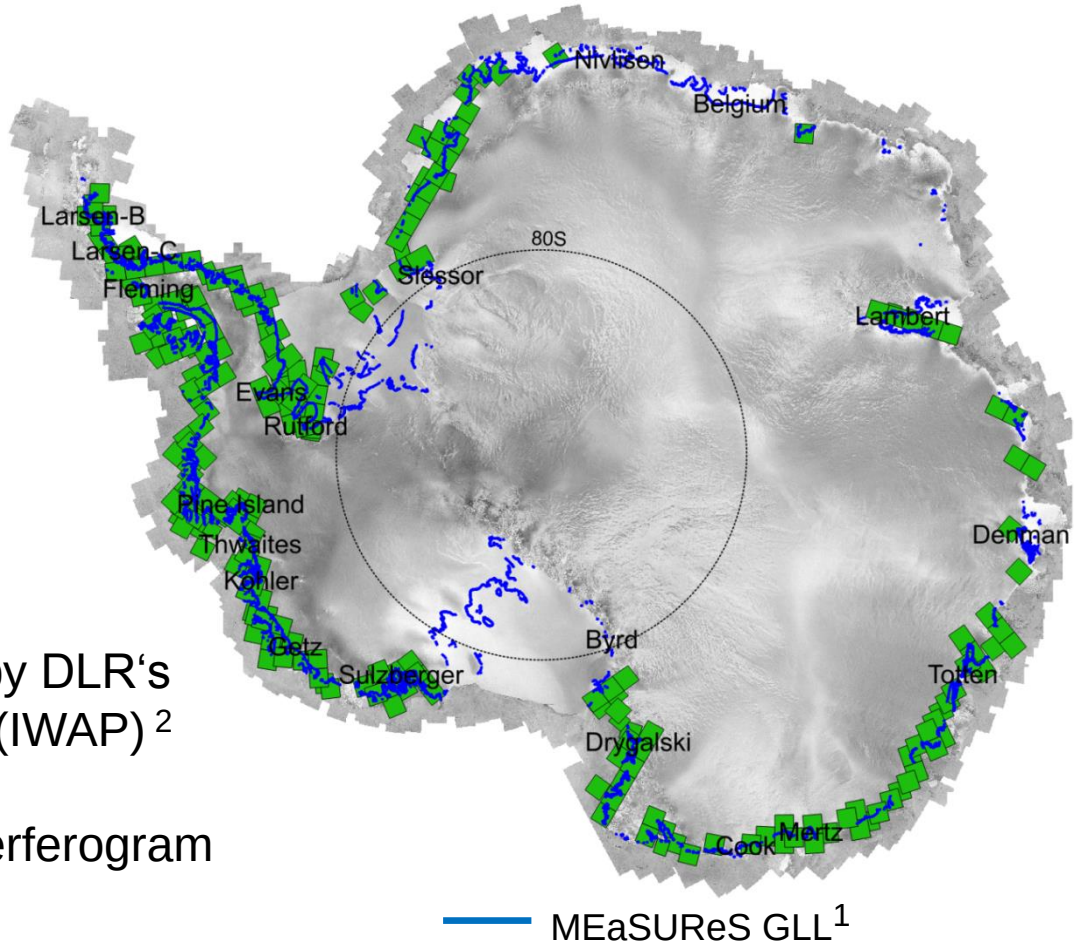
Double difference (t_1 & t_2 - t_2 & t_3)



- A minimum of three subsequent (t_1, t_2, t_3) repeat pass acquisitions (at different tidal conditions) from a single sensor are considered
- Topography corrected two single interferograms (t_1&t_2 and t_2&t_3) with horizontal ice flow and vertical deformation
- Double difference ((t_1&t_2 - t_2&t_3) interferogram eliminates horizontal ice flow components
- The remaining phase values appear in the differential interferogram as a typical pattern of a belt with dense fringes.

AIS_cci GLL generation from ERS-1/2

Time coverage
11.10.1995 – 15.05.1996



Status: ~1000 SLC products

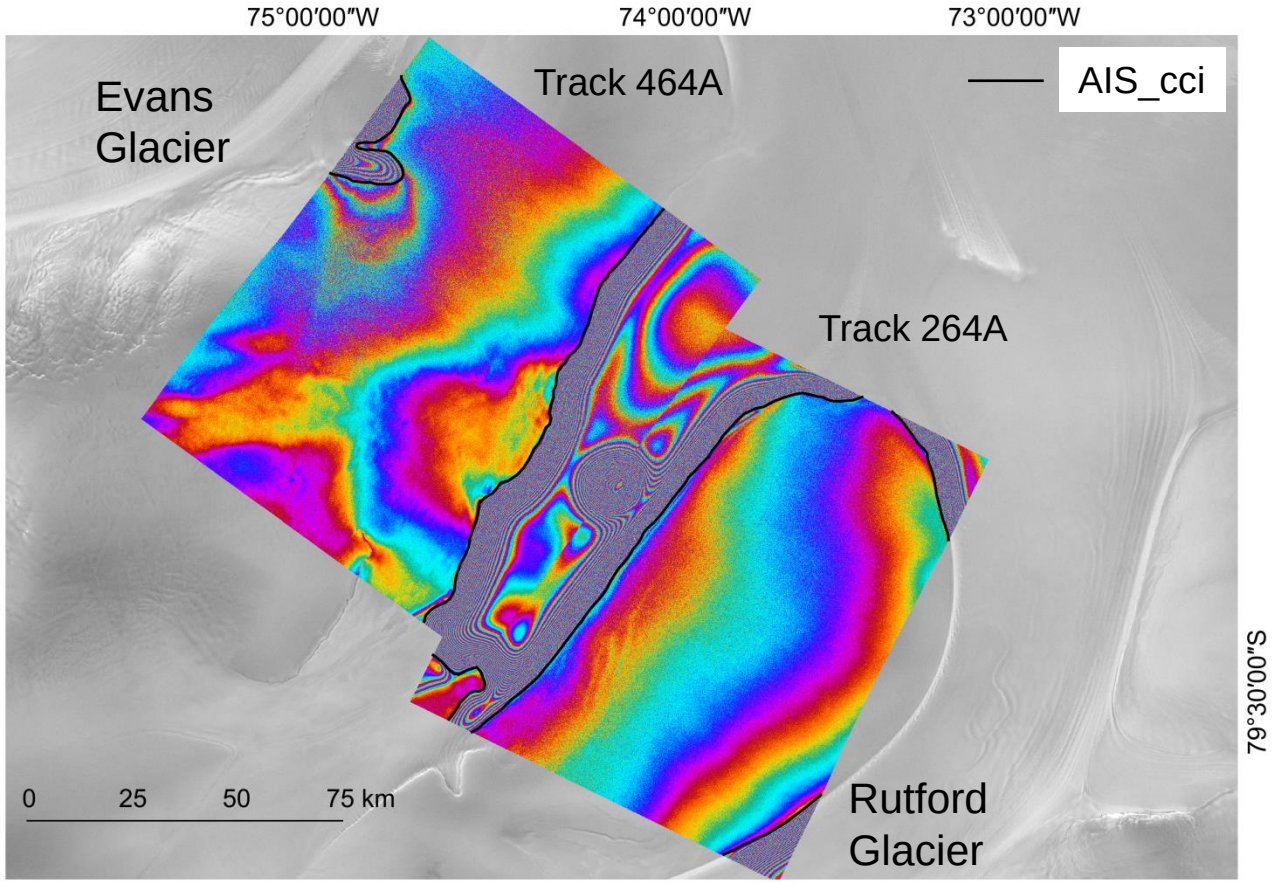
- Processed by ESA
- Delivered mid-February 2016
- InSAR processing is performed by DLR's Integrated Wide Area Processor (IWAP) [2]
- GLLs are derived from single interferogram

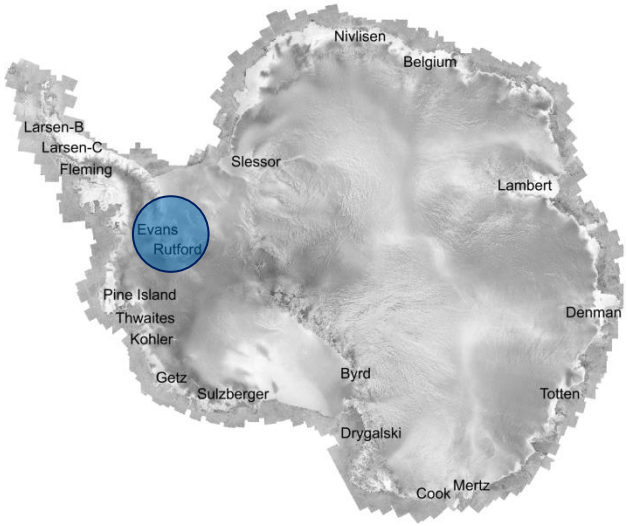
[1]Rignot et al, 2016. *MEaSUREs Antarctic Grounding Line from Differential Satellite Radar Interferometry, Version 2*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. doi: http://dx.doi.org/10.5067/IKBWW4RYHF1Q

[2]Rodriguez Gonzalez et al, 2013 The Integrated Wide Area Processor (IWAP): A Processor For Wide Area Persistent Scatterer Interferometry. In: Proceedings of ESA Living Planet Symposium 2013. ESA Living Planet Symposium 2013, 9–13 September 2013, Edinburgh, UK.

AIS_cci GLL generation from ERS-1/2 – Rutford Glacier

Single interferogram





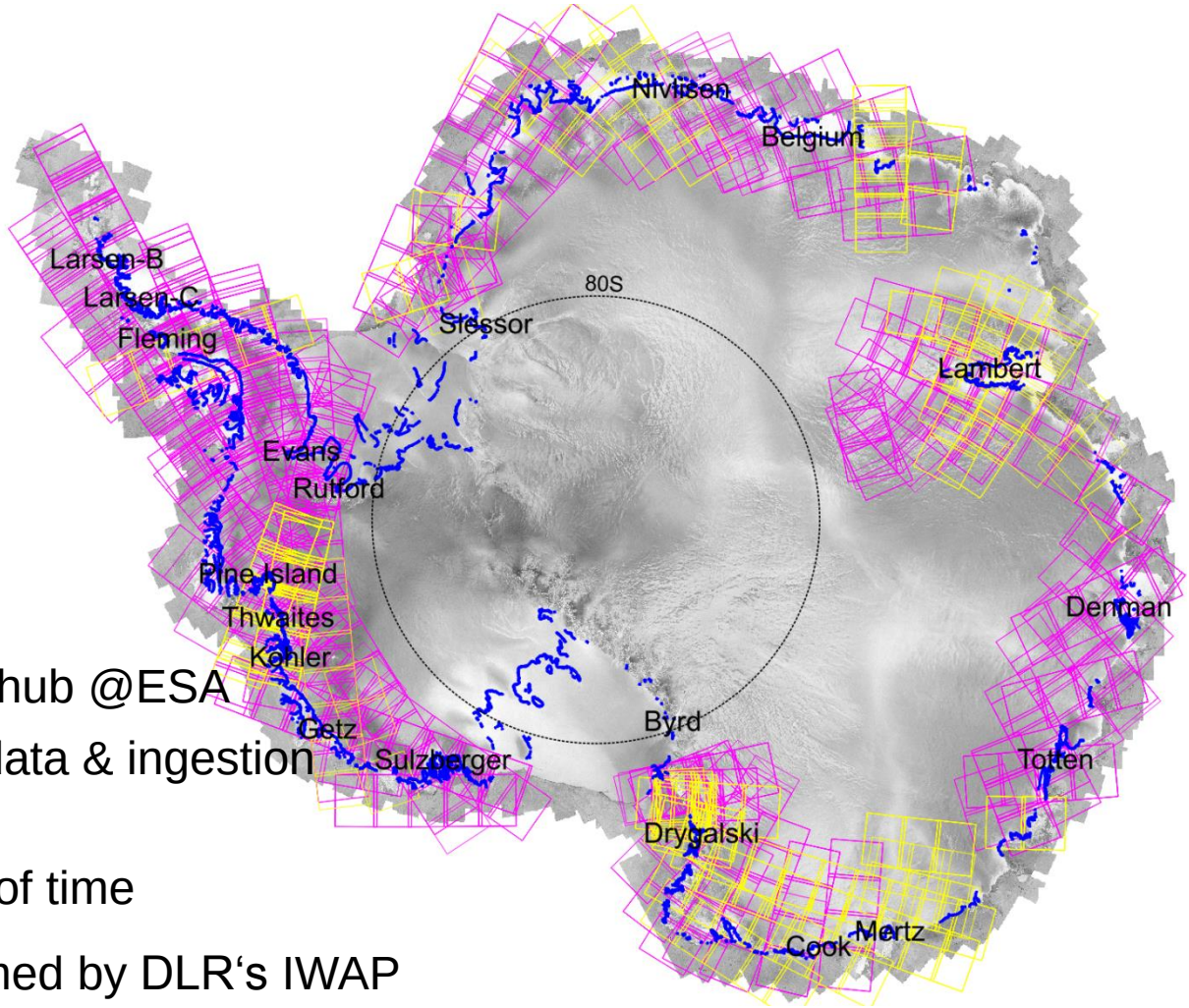
ERS-1/2 acquisitions information:

Track 464A
Master: 1995-11-03
Slave: 1995-11-04

Track 264A
Master: 1995-10-20
Slave: 1995-10-21

AIS_cci GLL generation from Sentinel – 1A/B

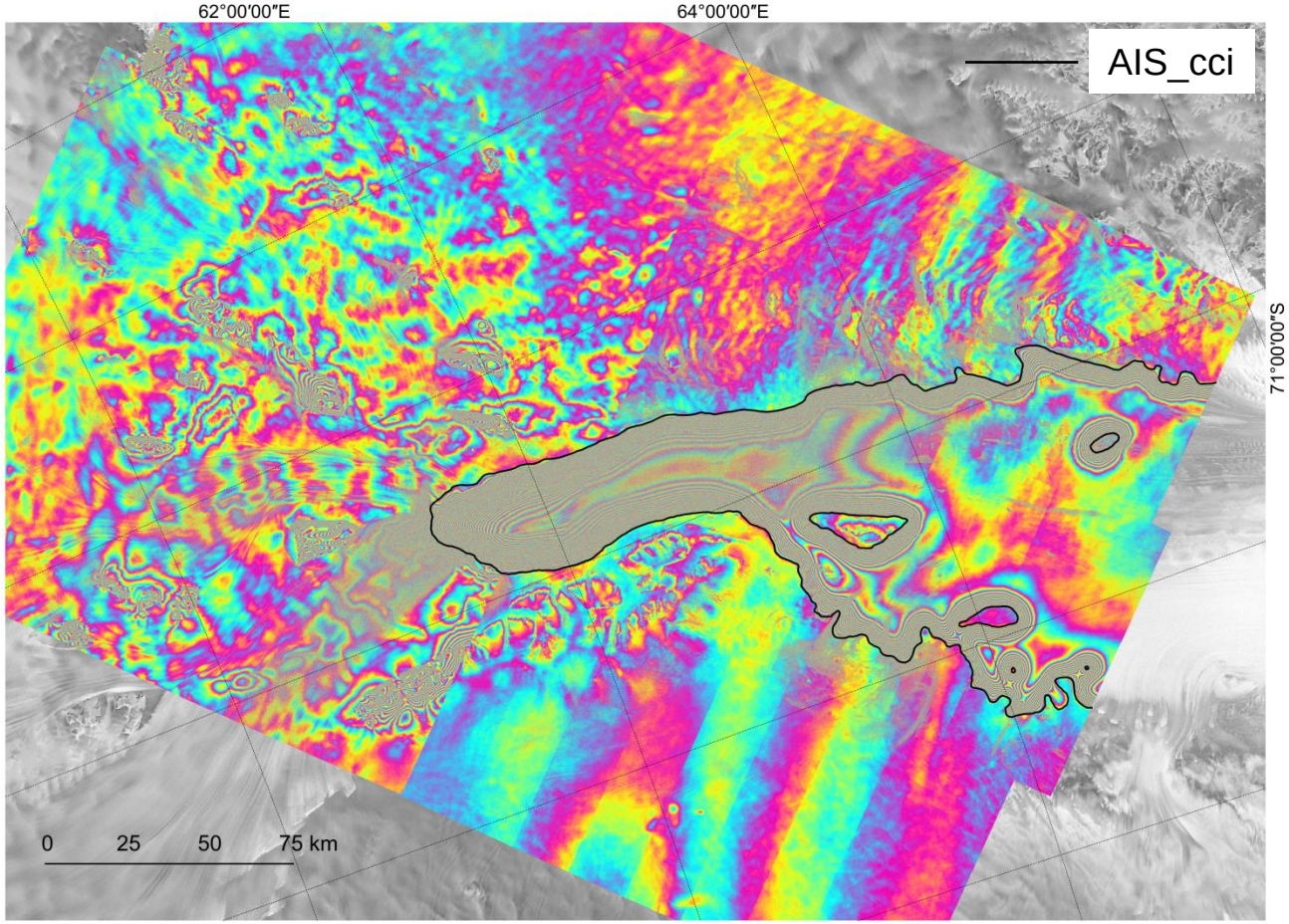
Time coverage
- 2015 – 2017
- 12 days repeat pass triplets
- 6 days repeat pass triplets

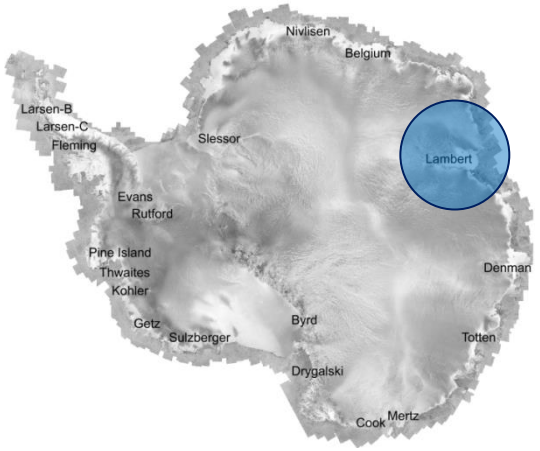


Status: ~1450 SLC products
- monitoring the S1A science hub @ESA
- auto download new S1A/B data & ingestion in the Input Data Pool
  - within a specific period of time
- InSAR processing is performed by DLR‘s IWAP
- GLLs are derived from double difference interferogram

AIS_cci GLL generation from Sentinel – 1A/B Lambert Glacier

Double difference interferogram from 6 days triplets





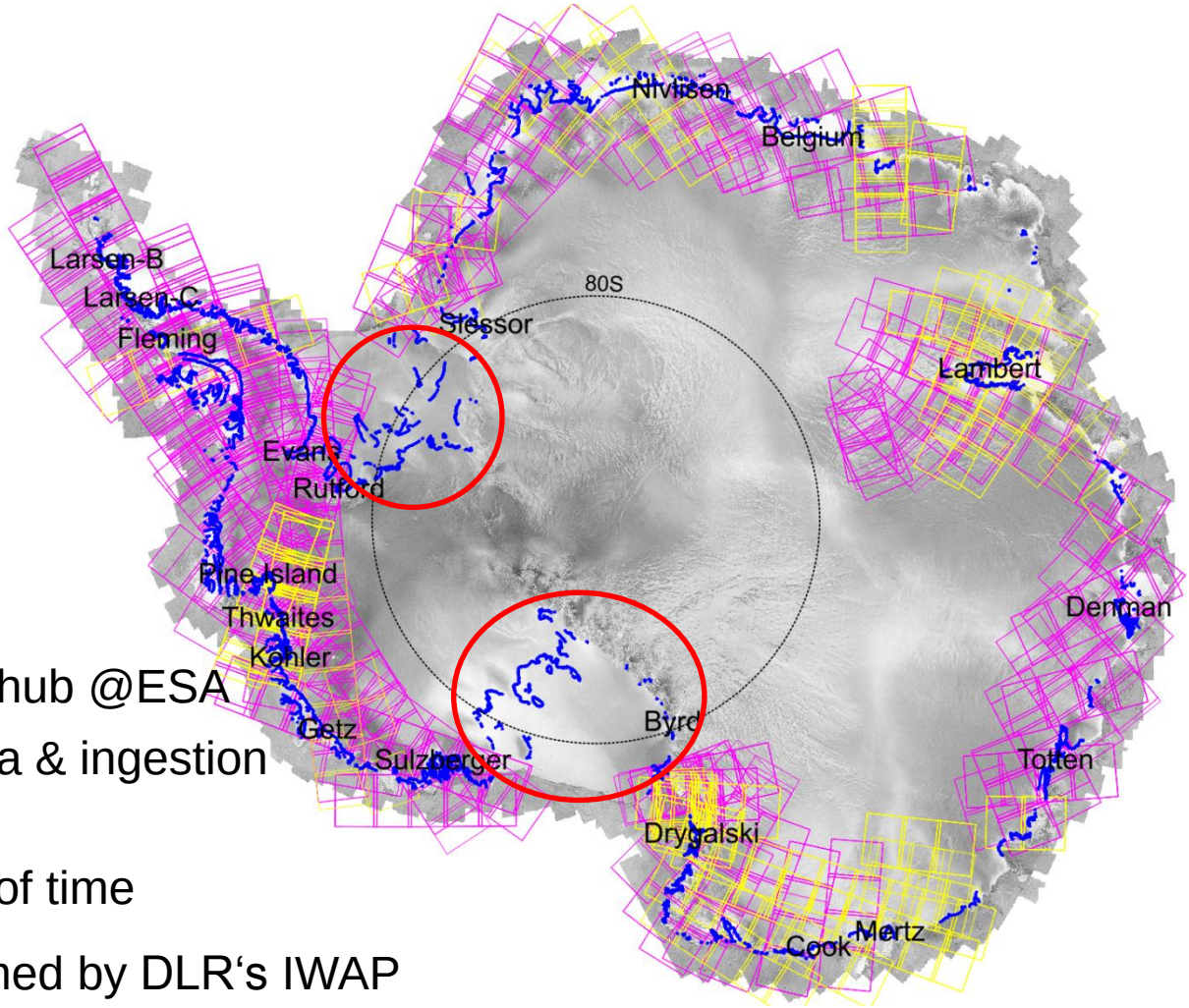
Sentinel-1A/B acquisition dates:

	2017.03.29
Master scene	**2017.04.04**
	2017.04.10

Rel. Orb: 003
Interferometric Wide Swath
Descending orbit
Right looking

AIS_cci GLL generation from Sentinel – 1A/B

Time coverage
- 2015 – 2017
- 12 days repeat pass triplets
- 6 days repeat pass triplets



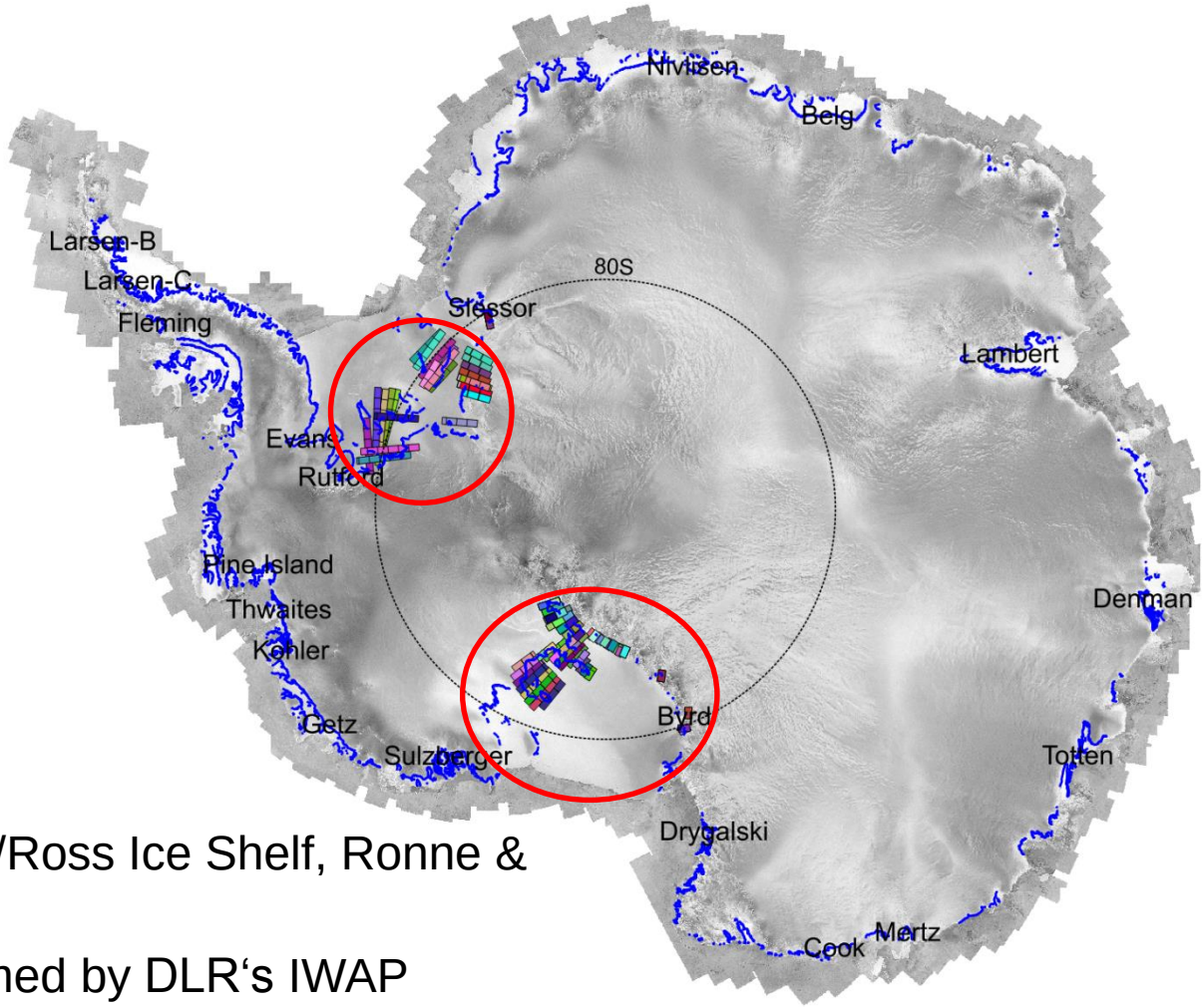
Status: ~1450 SLC products
- monitoring the S1A science hub @ESA
- auto download new S1A data & ingestion in the Input Data Pool
  - within a specific period of time
- InSAR processing is performed by DLR‘s IWAP
- GLLs are derived from double difference interferogram

AIS_cci GLL generation from TerraSAR-X

Time coverage

- 2009-2017
- 11 days repeat pass triplets

- Right (nominal) and left looking acquisitions combined



Status: ~500 SLC products

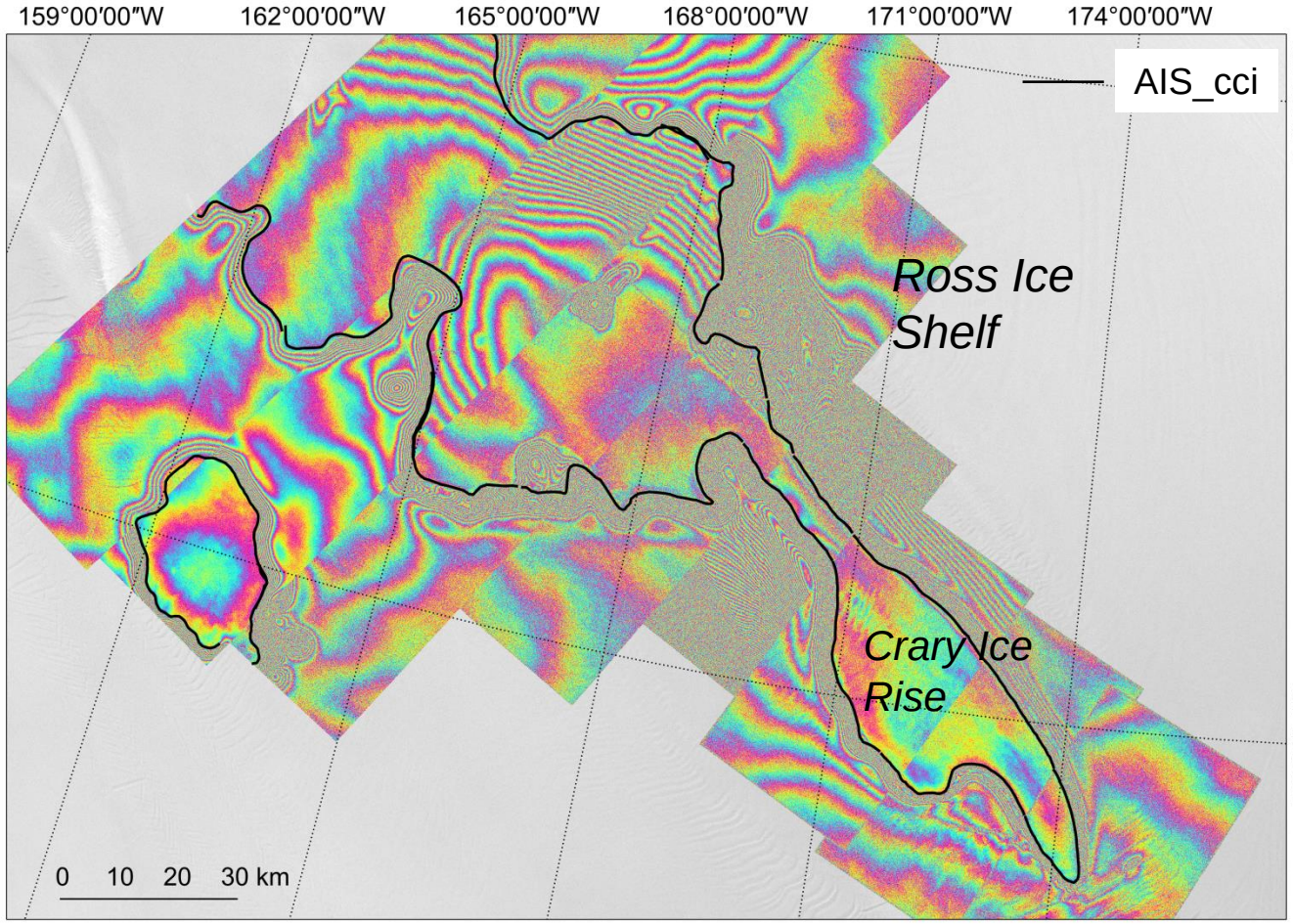
- SLCs in Transantarctic Mts./Ross Ice Shelf, Ronne & Filchner Ice Shelves
- InSAR processing is performed by DLR‘s IWAP
- GLLs are derived from double difference interferogram

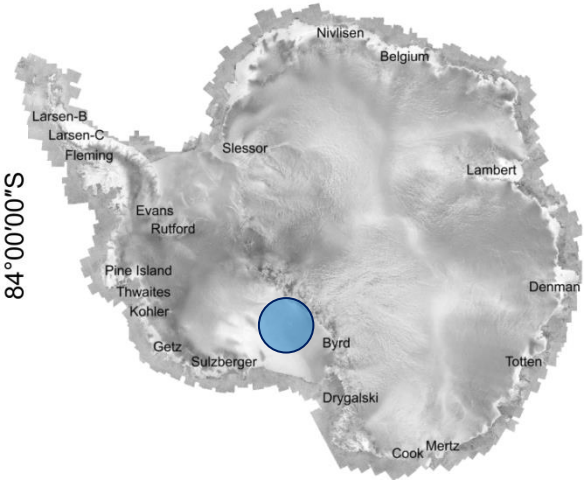
MEaSUReS GLL

TerraSAR-X data were delivered from German Aerospace Center (DLR) under the proposals HYD1421 and HYD3056

AIS_cci GLL generation from TerraSAR-X – Crary Ice Rise

Double difference interferogram from 11 days triplets





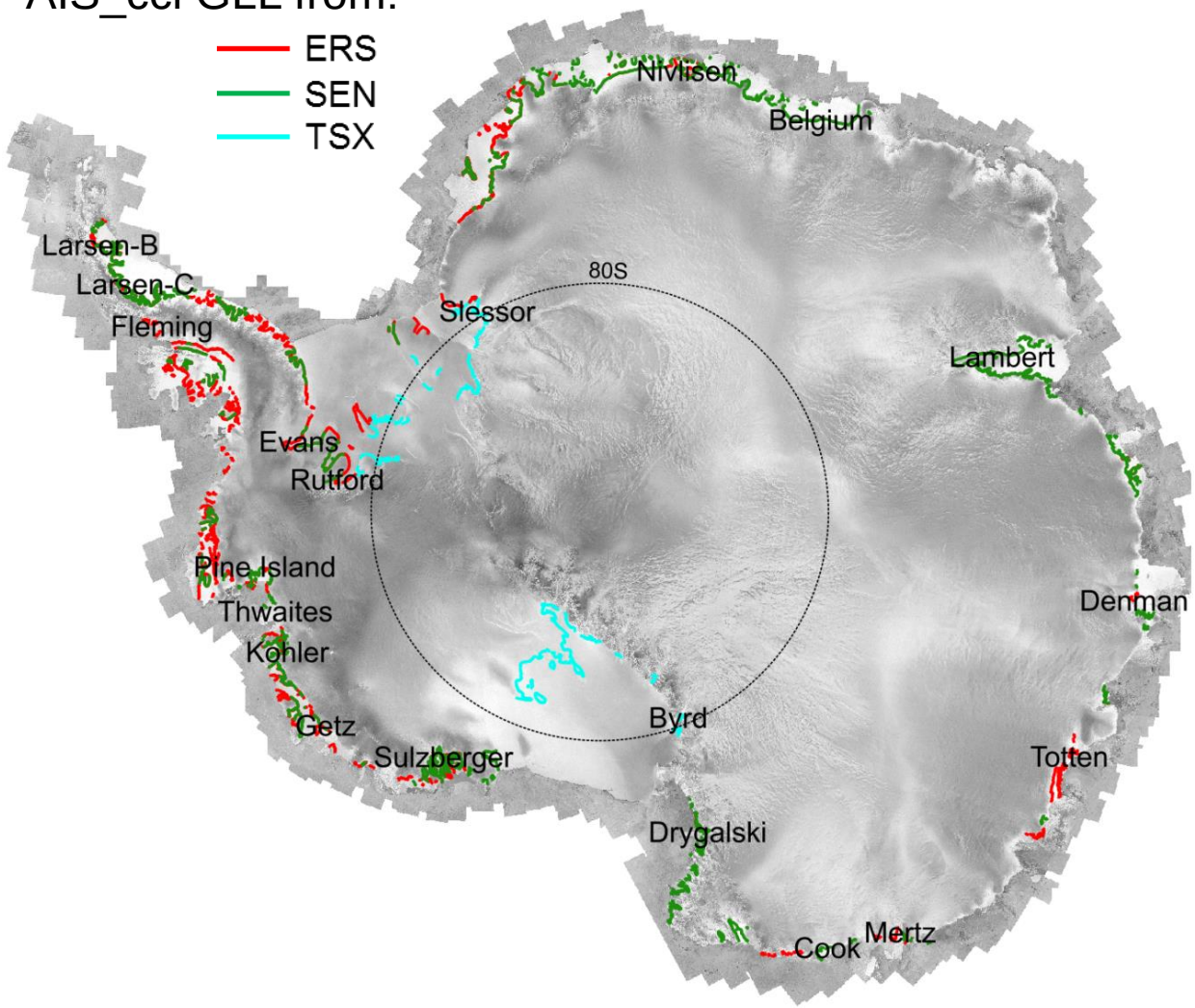
TerraSAR-X acquisitions period: 2012 – 2016

Left looking

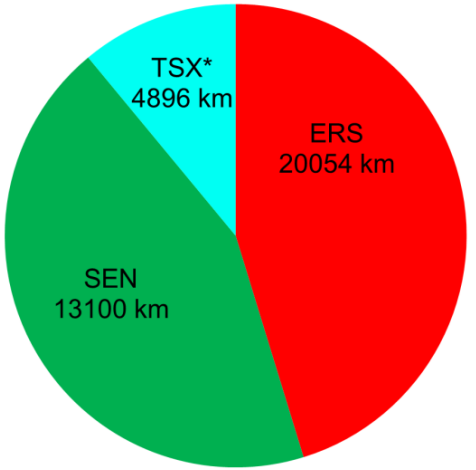
Stripmap

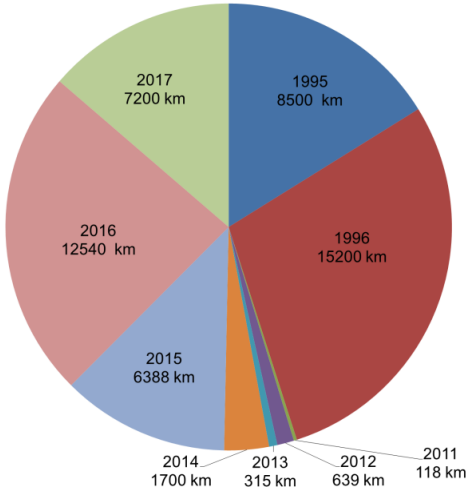
AIS_cci GLL product generation - status May 2017

AIS_cci GLL from:



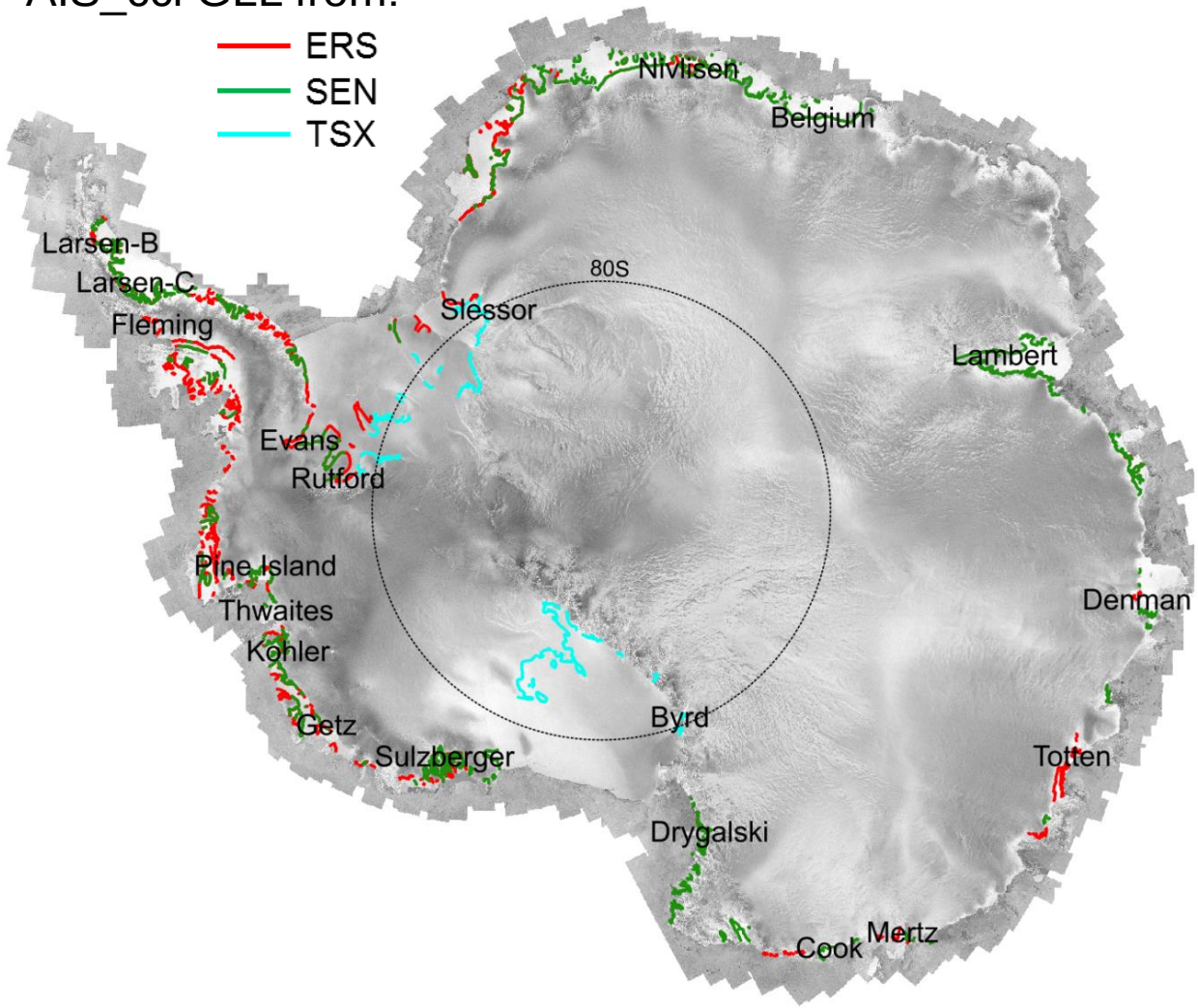
Total derived GLL:
52600 km





AIS_cci GLL product formats

AIS_cci GLL from:



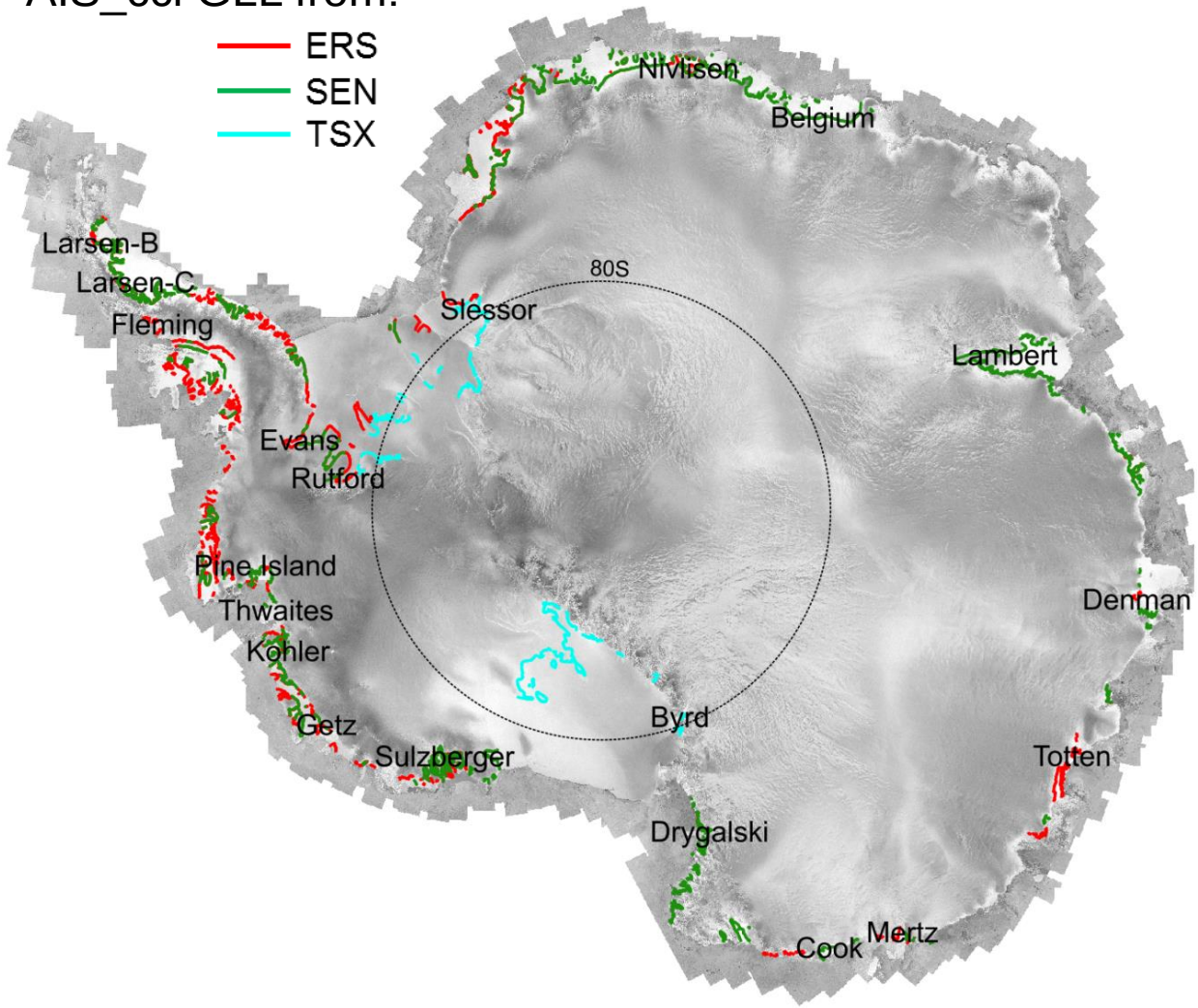
ESRI shapefile (.shp) for GIS user and further geospatial analyses

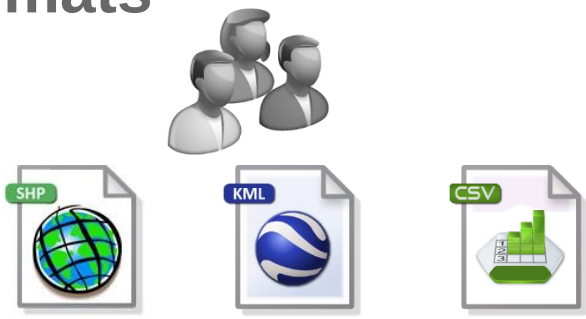
Google Earth (kml) for quick visualization or inspection

WKT format (plain text)

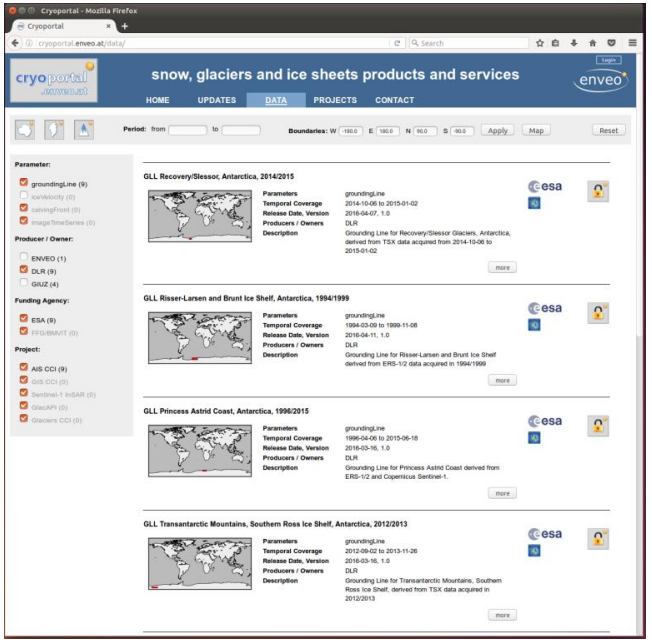
AIS_cci GLL product formats

AIS_cci GLL from:



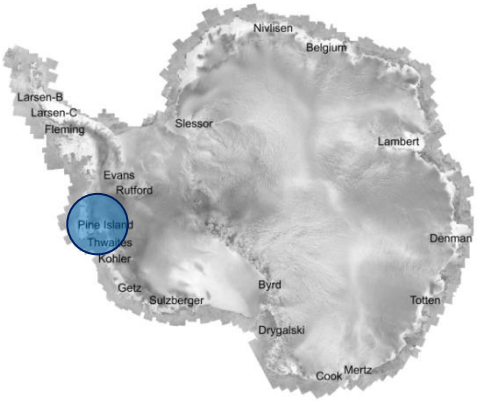


ENVEO's Cryoportal
(http://cryoportal.enveo.at)

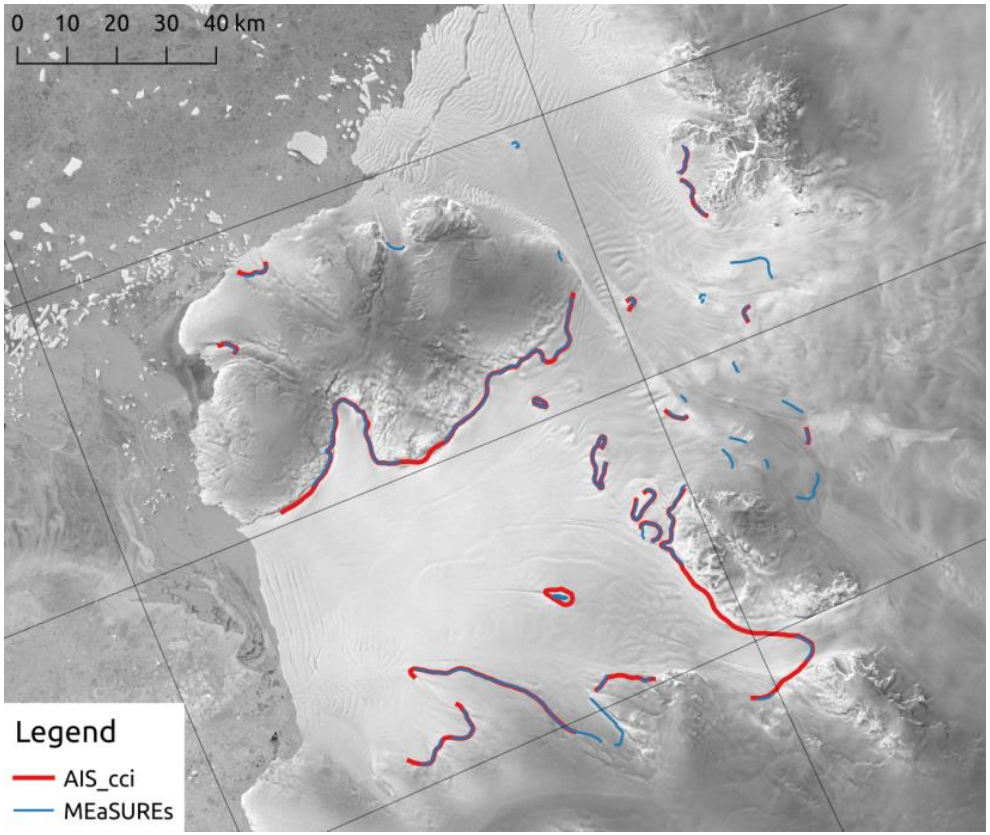


GLL Product Validation and inter-comparison

Comparison between AIS_cci GLL and MEaSUReS GLL
with identical SAR acquisition



GLL segments in the Dotson/Crosson Ice Shelves



Sentinel-1A/B acquisition dates:

	2014.11.23
Master scene	**2014.12.05**
	2014.12.17

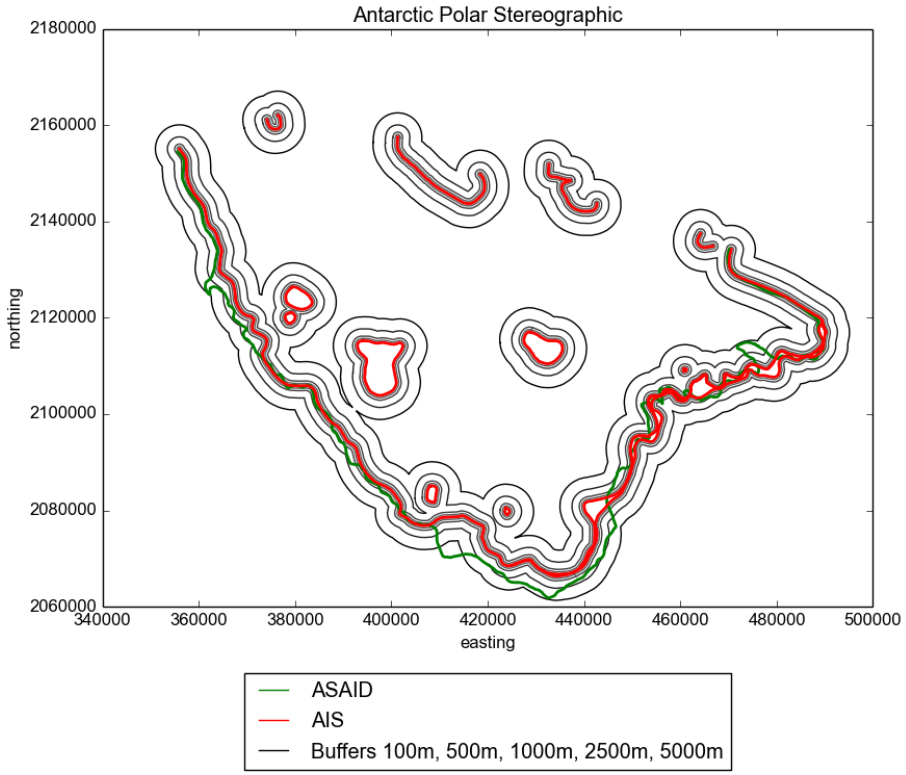
Rel. Orb: 003
Interferometric Wide Swath
Ascending orbit
Right looking

Scheuchl et al, 2016, Grounding line retreat of Pope, Smith, and Kohler Glaciers, West Antarctica, measured with Sentinel-1a radar interferometry data, Geophys. Res. Lett., 43, 8572–8579, doi:10.1002/2016GL069287

GLL Product Validation and inter-comparison

Buffered method

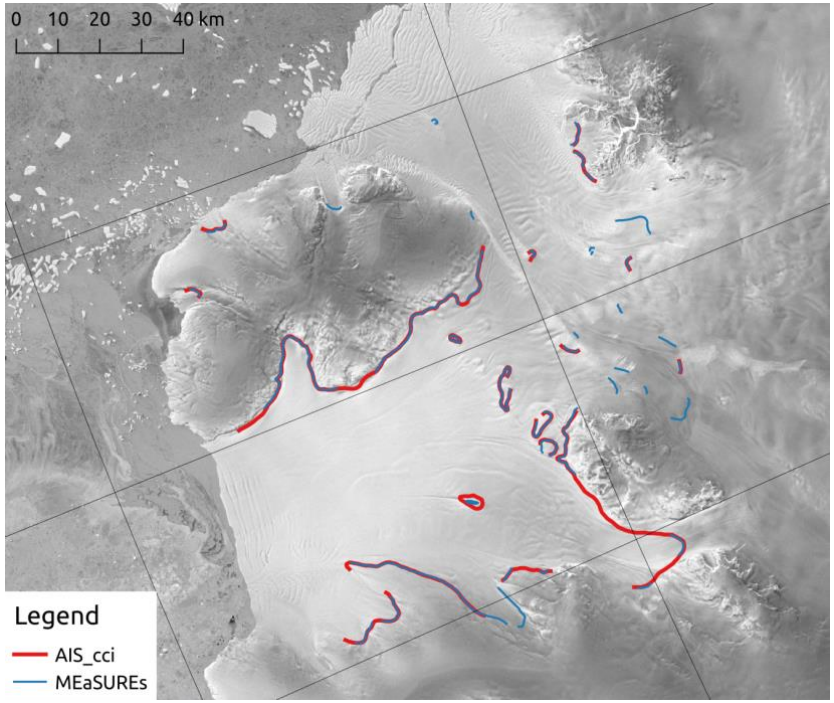
- Create buffer objects around the reference line (AIS_cci GLL or ASAID GLL)
- Calculate the percentage of overlap with the target line (AIS_cci GLL or ASAID GLL) for all buffer distances (100m, 500m, 1000m …)



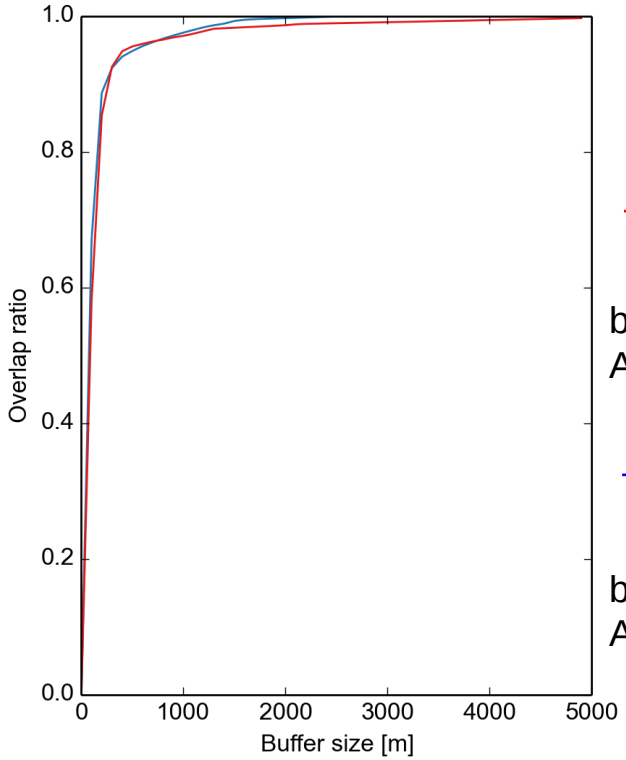
Antarctic Surface Accumulation and Ice Discharge (ASAID)

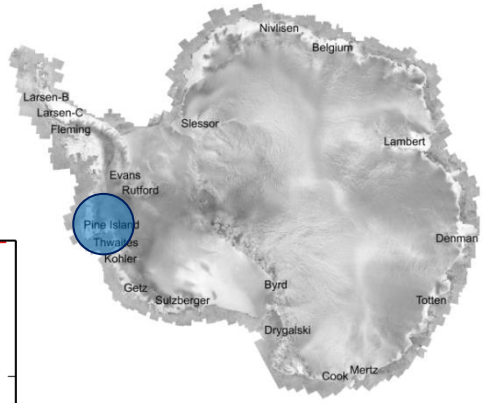
GLL Product Validation and inter-comparison

Comparison between AIS_cci GLL and MEaSUReS GLL
with identical SAR acquisition



with matching counterpart





MEaSUREs GLL
as reference line

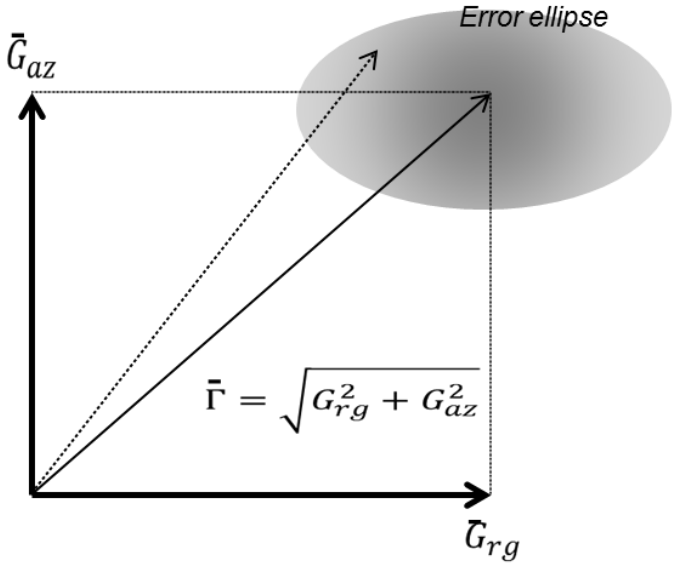
buffer around MEaSUREs
Avg. difference = ~129 m

AIS_cci GLL as
reference line

buffer around AIS_cci
Avg. difference = ~172 m

- The overlapped GLLs are ~95% within 500m buffer of both datasets

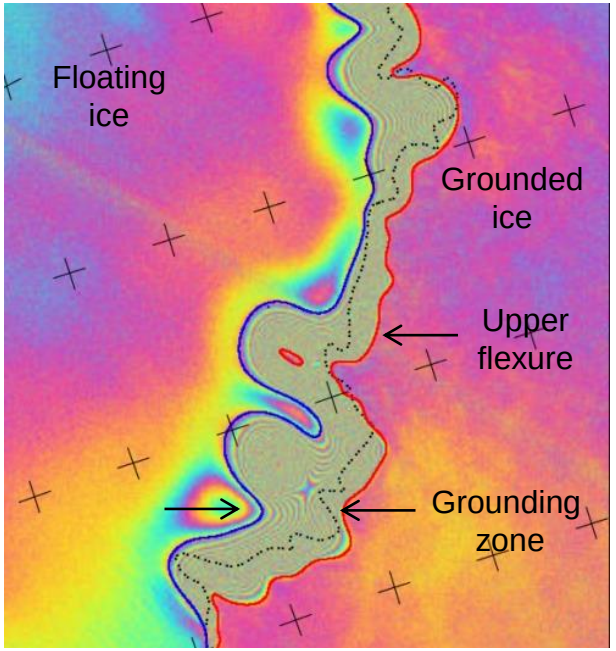
AIS_cci GLL generation – Algorithm development



$\bar{G}_{az}$ Deformation gradient in azimuth [cm/km]

$\bar{G}_{rg}$ Deformation gradient in range [cm/km]

Upper limit of flexures are delineated by manual interpretation

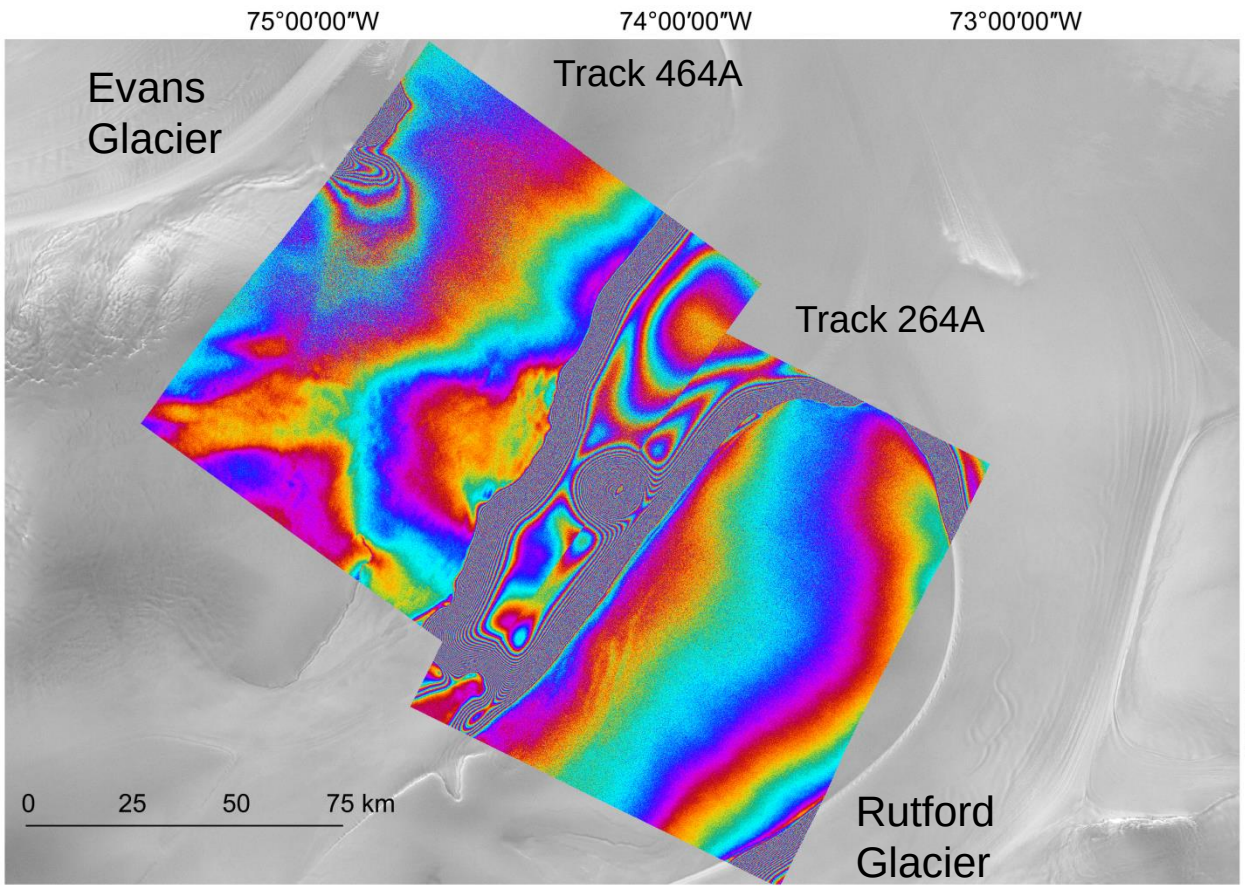


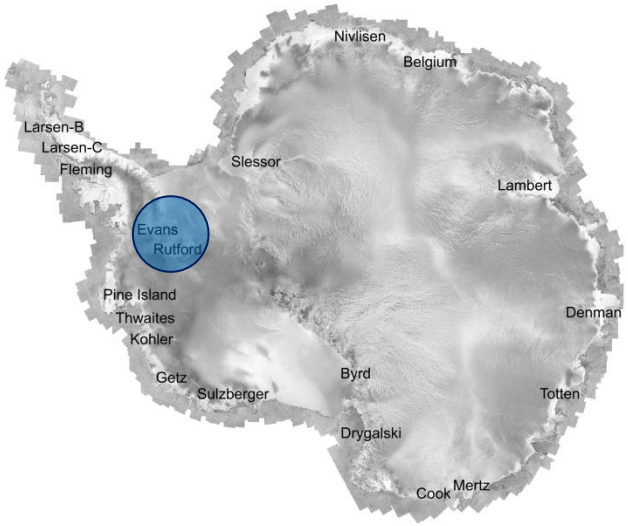
- Operates in complex domain over data patches
- Calculate magnitude of deformation gradient in LOS
- The spatial gradient of deformation in LOS connected to GLL, corresponds to the main fringe frequency

14:00hr Measuring Strain and Rotation using InSAR. Example of a Glacier Flow, Parizzi et al

AIS_cci GLL generation – Fringe frequency

case 1: good coherence and simple shape





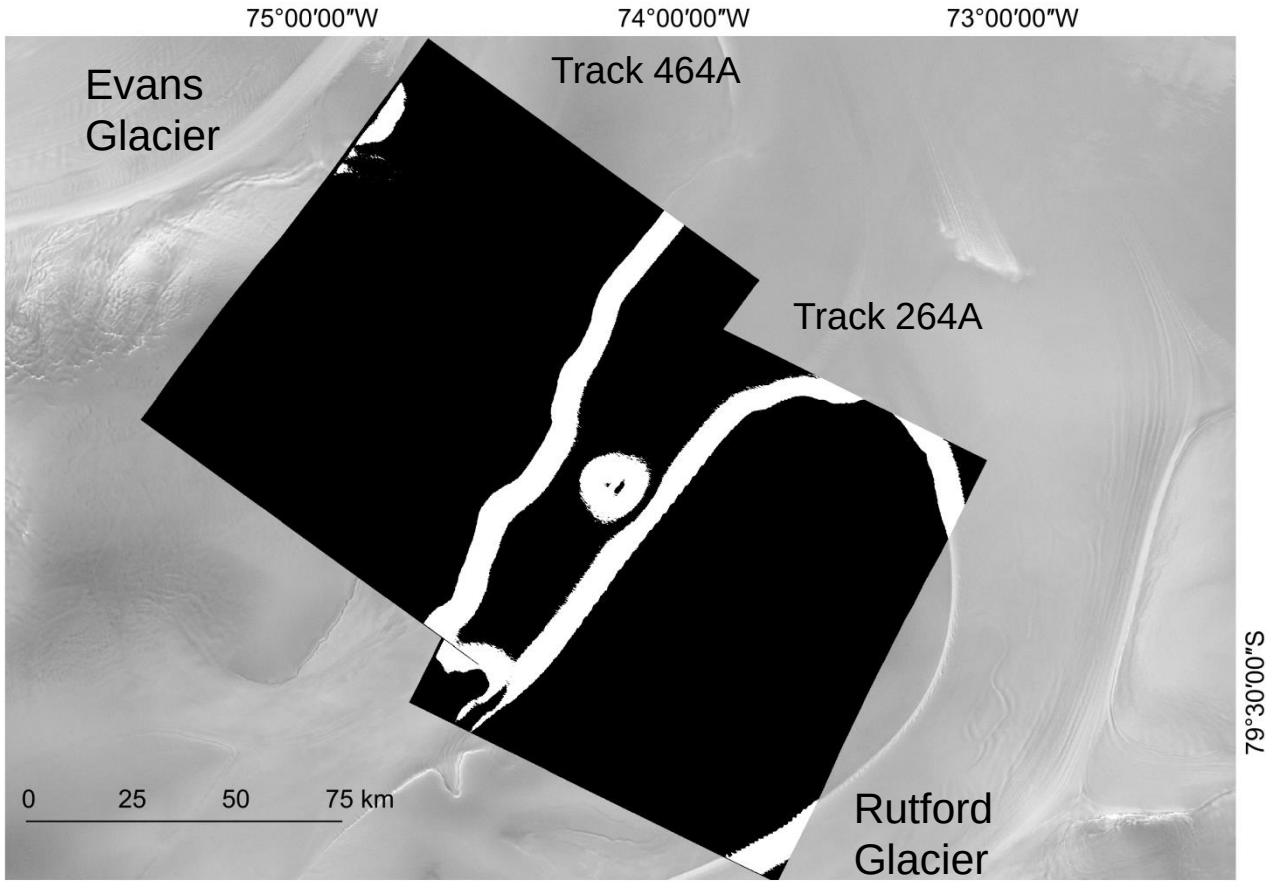
ERS-1/2 acquisitions information:

Track 464A
Master: 1995-11-03
Slave: 1995-11-04

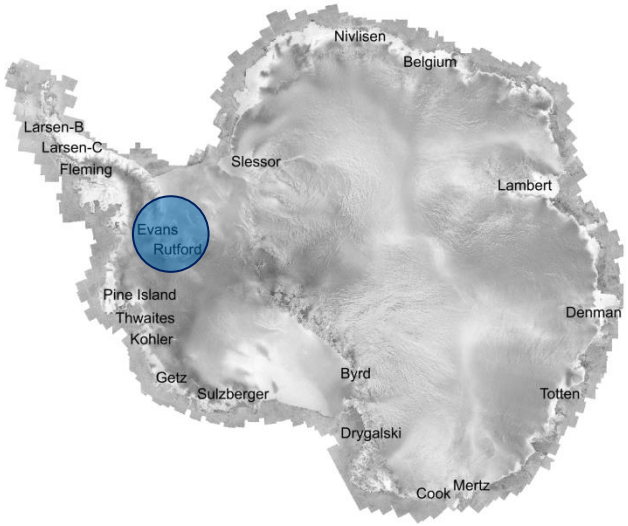
Track 264A
Master: 1995-10-20
Slave: 1995-10-21

AIS_cci GLL generation – Fringe frequency

case 1: good coherence and simple shape



Gradients amplitude 4-5 [cm/km]



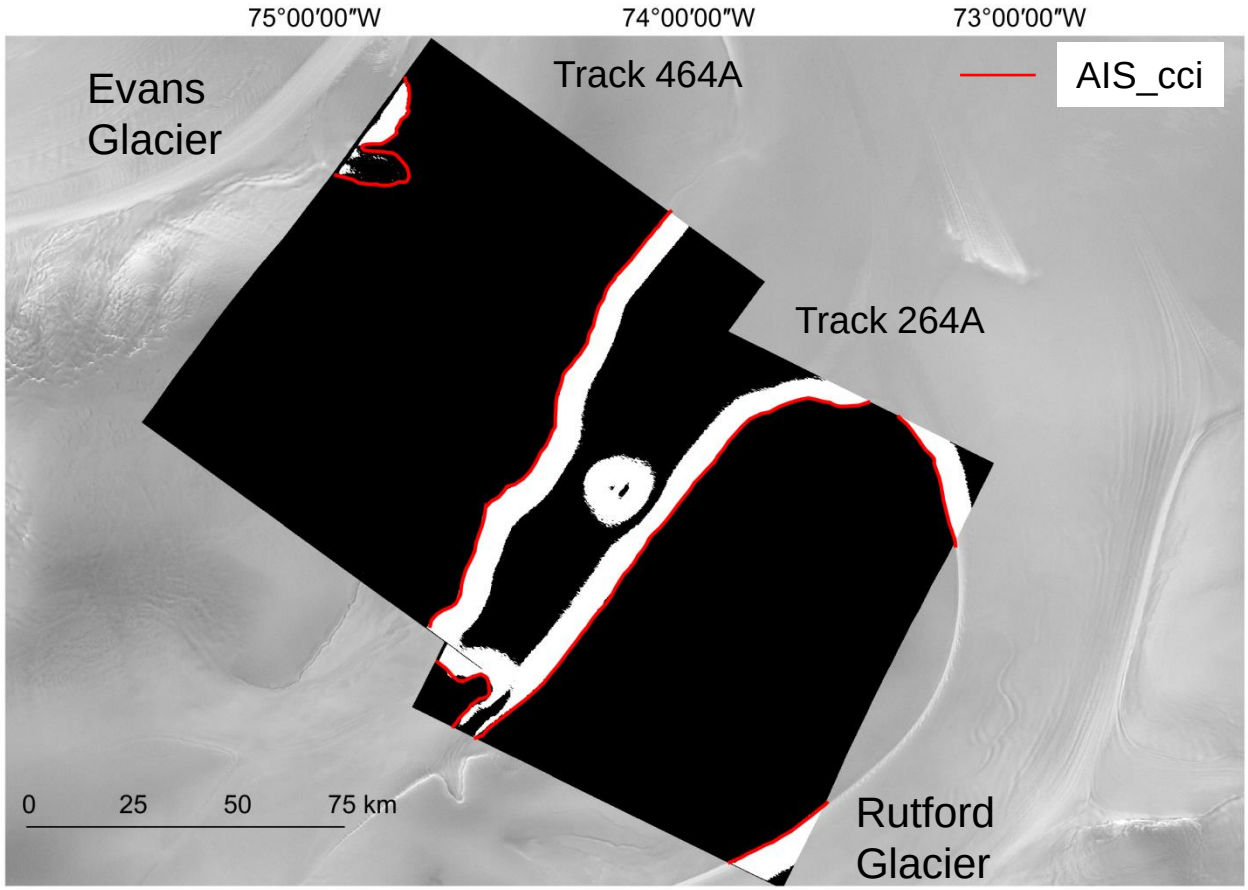
ERS-1/2 acquisitions information:

Track 464A
Master: 1995-11-03
Slave: 1995-11-04

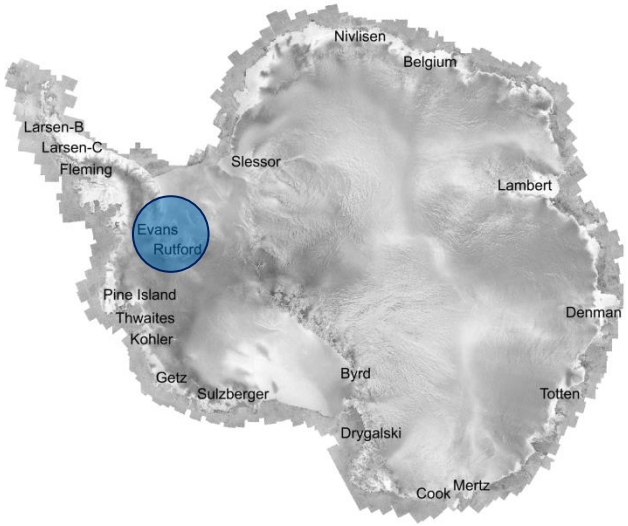
Track 264A
Master: 1995-10-20
Slave: 1995-10-21

AIS_cci GLL generation – Fringe frequency

case 1: good coherence and simple shape



Gradients amplitude 4-5 [cm/km]



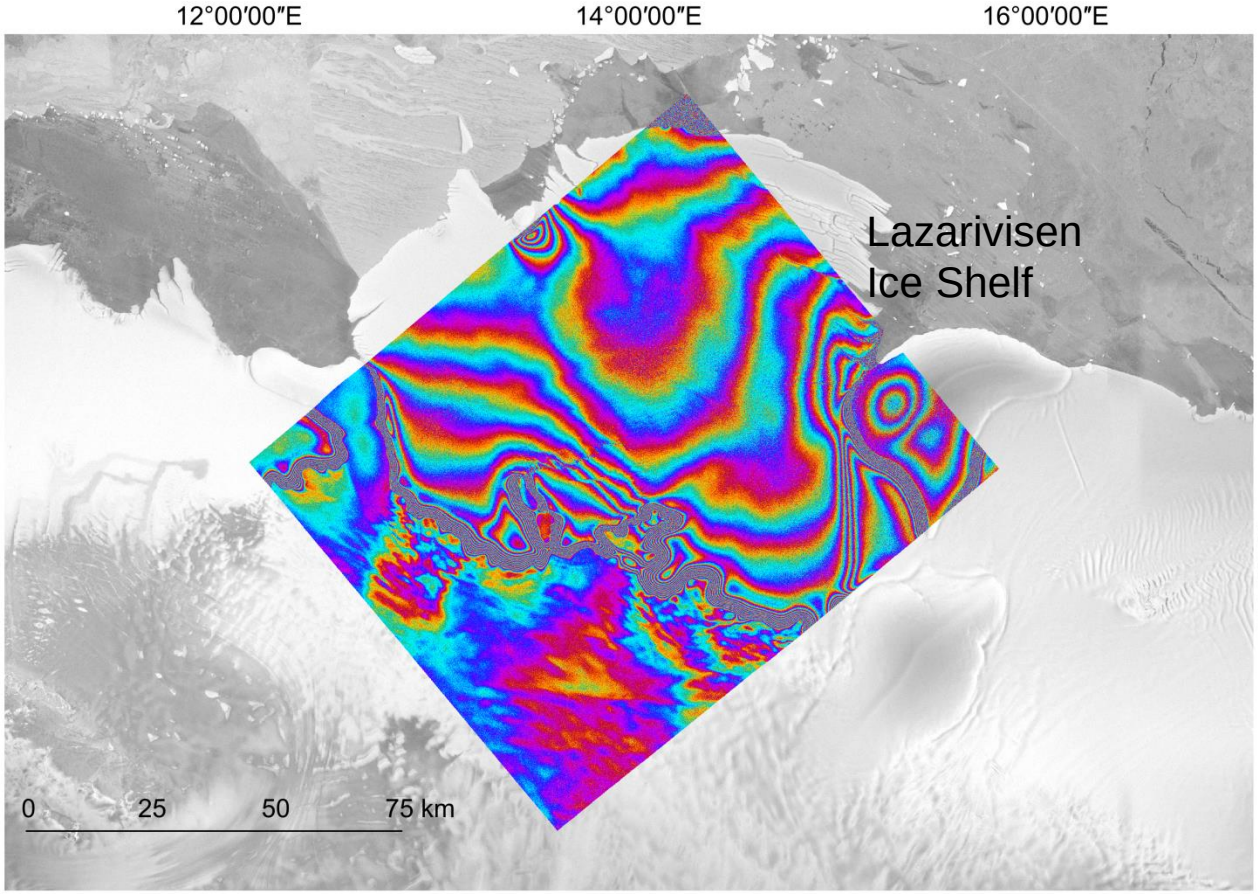
ERS-1/2 acquisitions information:

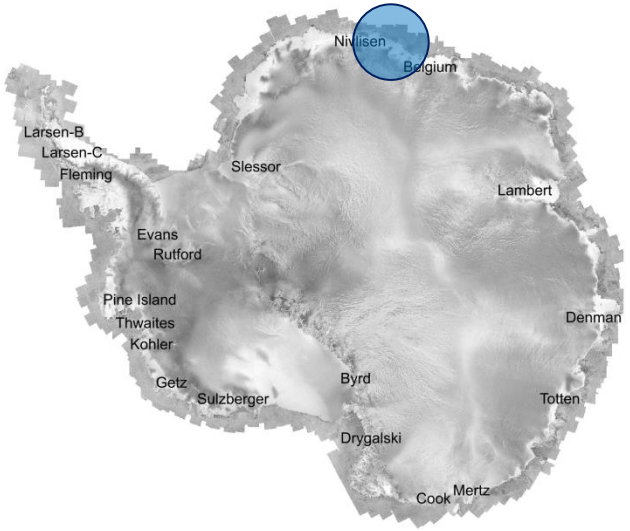
Track 464A
Master: 1995-11-03
Slave: 1995-11-04

Track 264A
Master: 1995-10-20
Slave: 1995-10-21

AIS_cci GLL generation – Fringe frequency

case 2: good coherence and complex shape

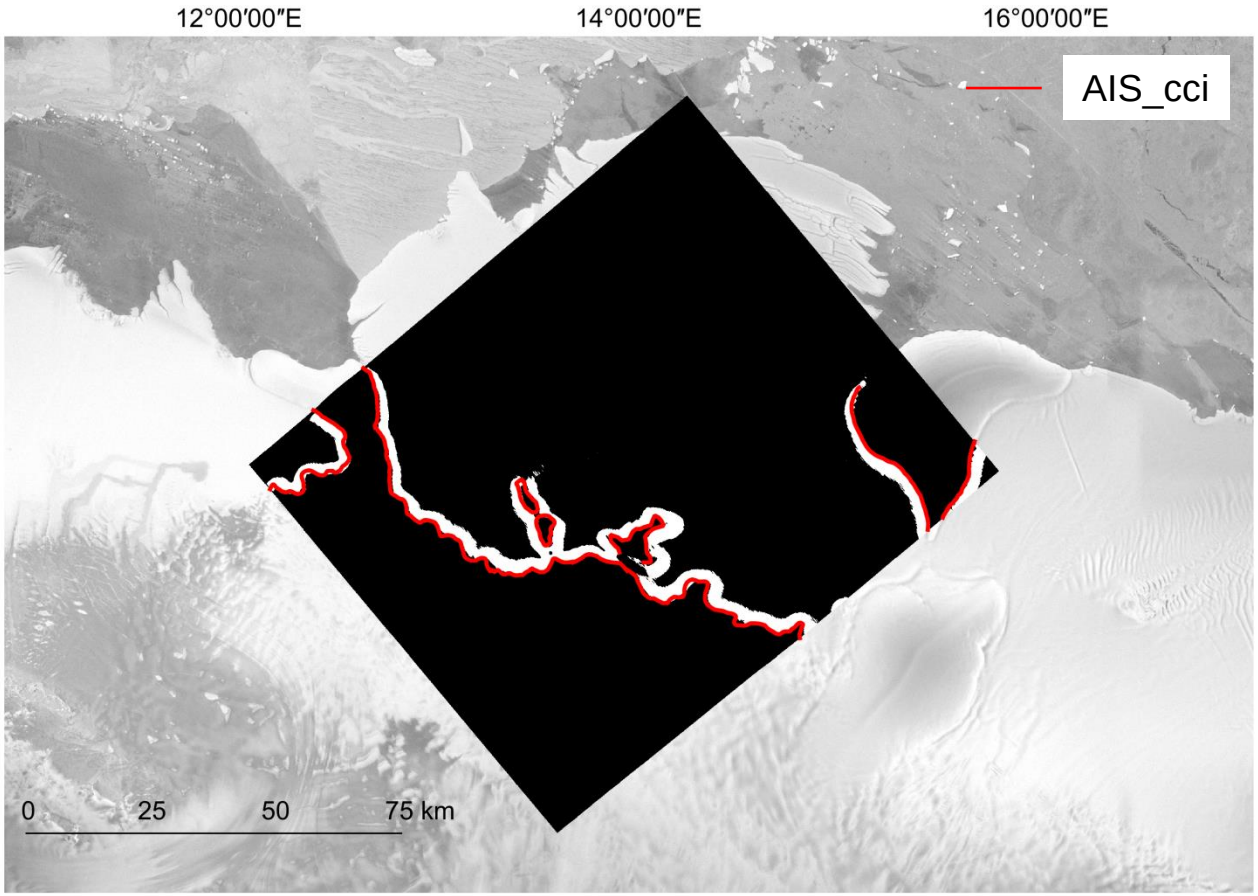


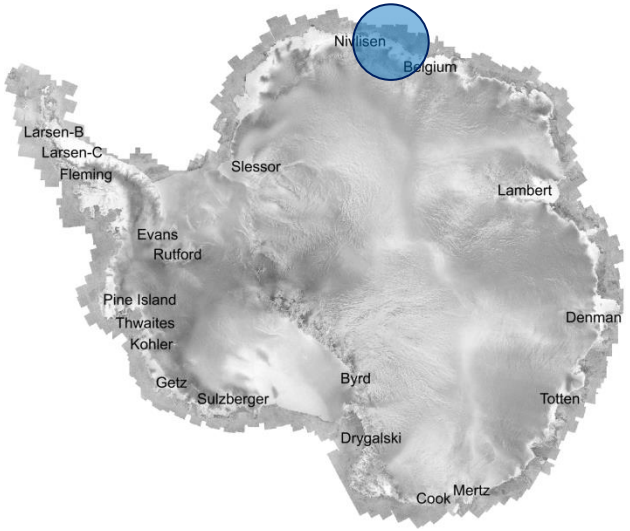


ERS-1/2 acquisitions information:

Track 163D
Master: 1996-04-05
Slave: 1996-04-06

AIS_cci GLL generation – Fringe frequency





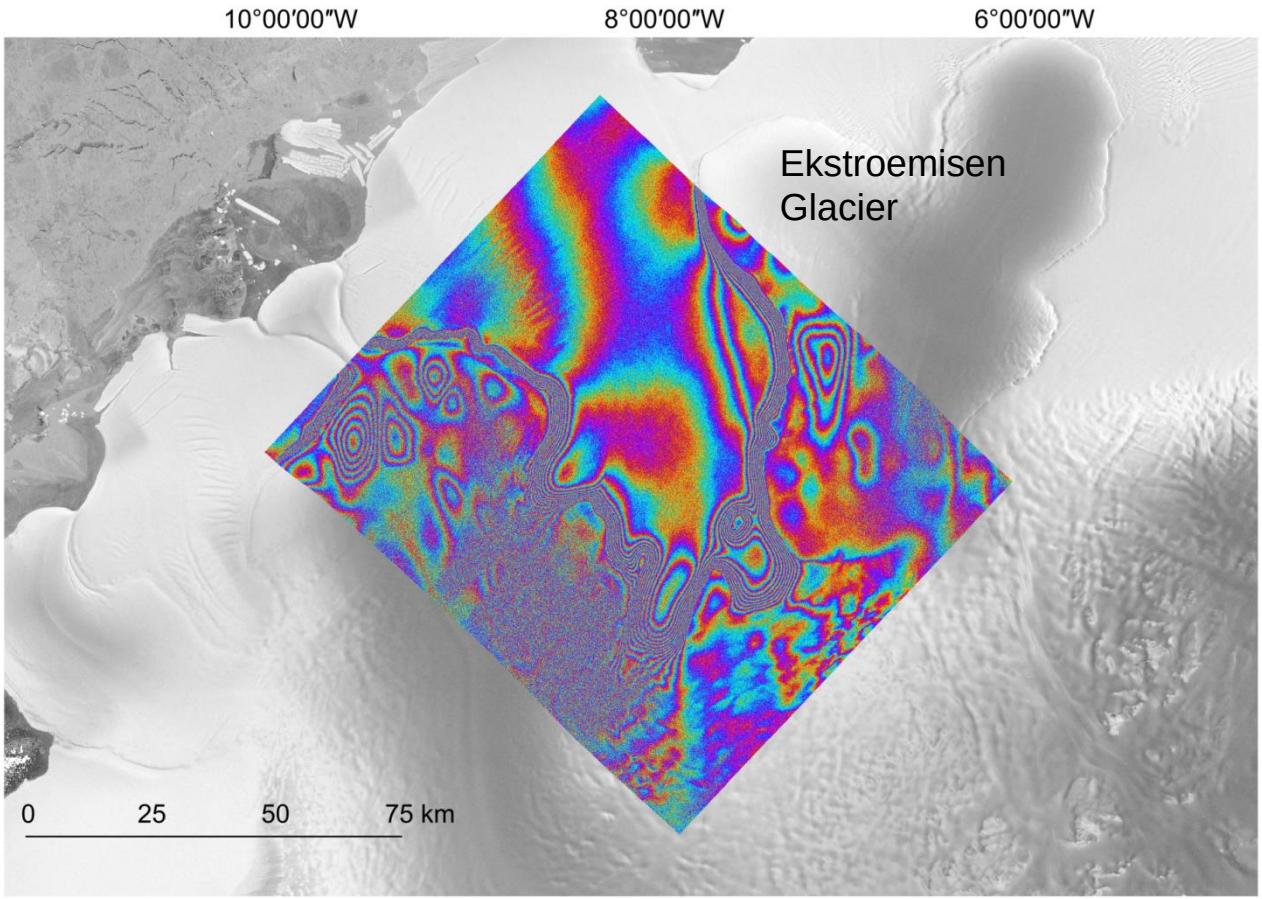
ERS-1/2 acquisitions information:

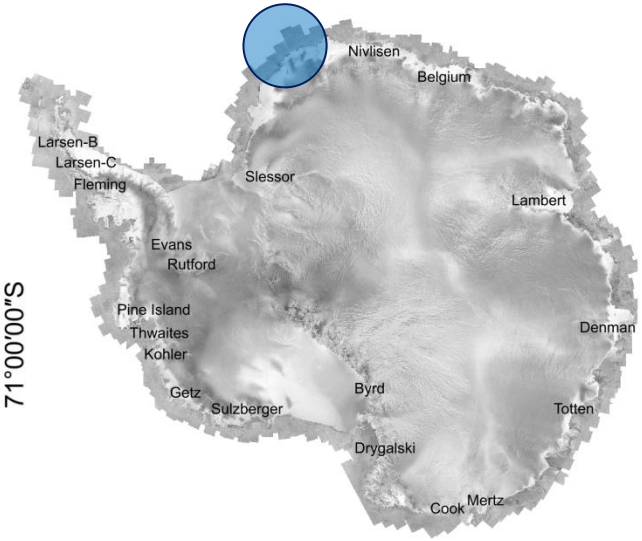
Track 163D
Master: 1996-04-05
Slave: 1996-04-06

Gradients amplitude 4-6 [cm/km]

AIS_cci GLL generation – Fringe frequency

case 3: bad coherence and complex shape



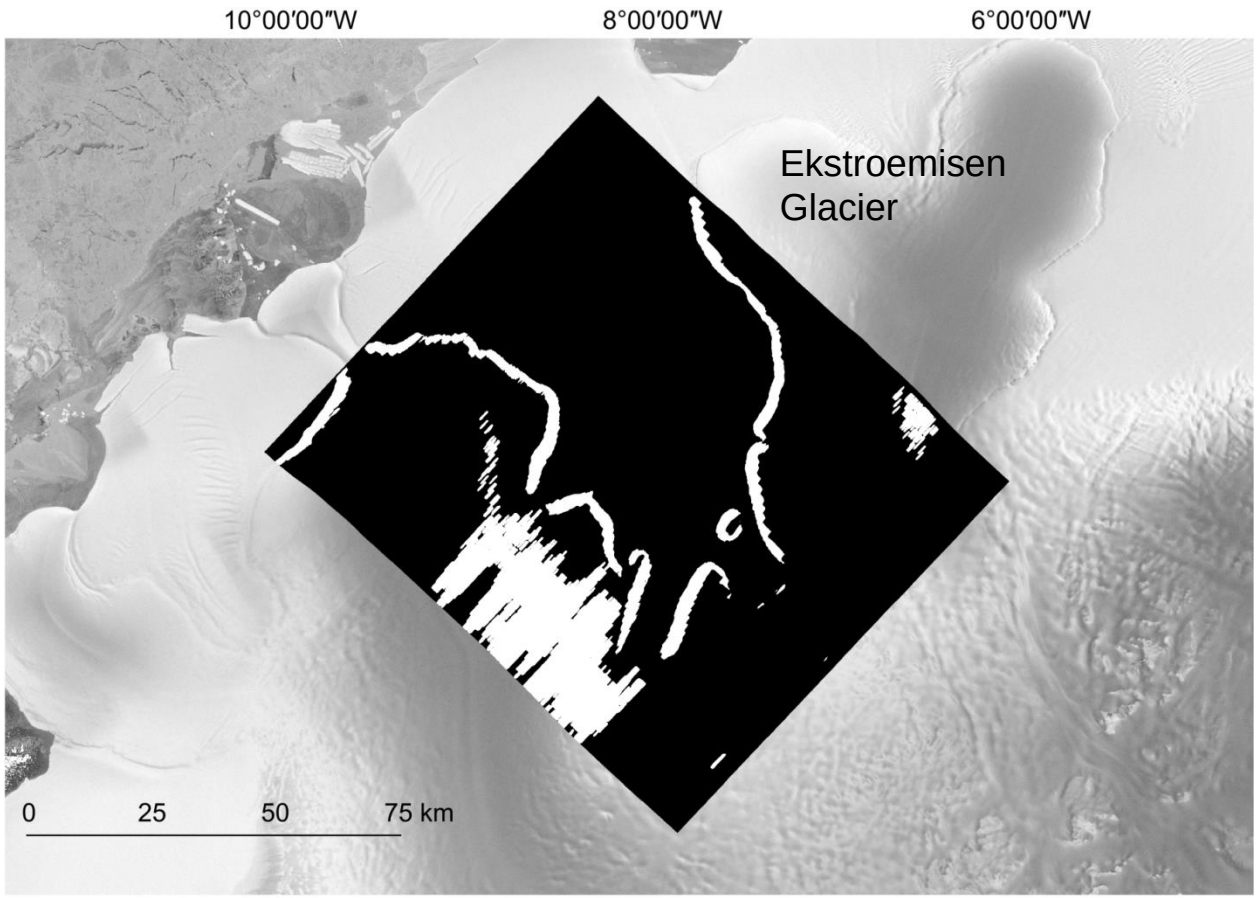


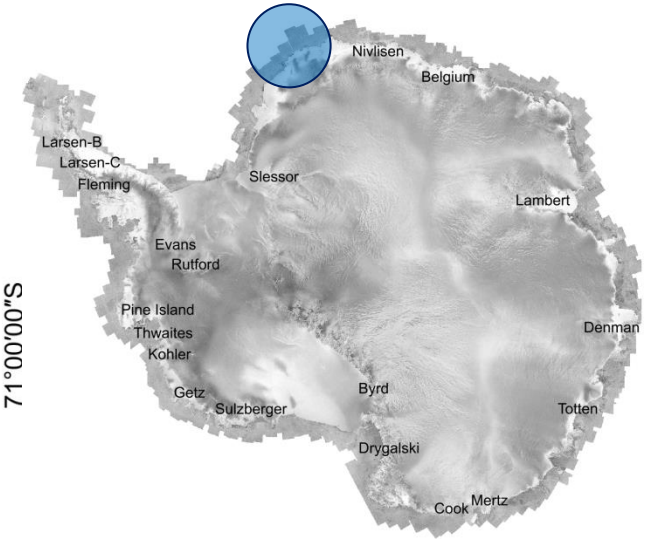
ERS-1/2 acquisitions information:

Track 002A
Master: 1996-02-19
Slave: 1996-02-20

AIS_cci GLL generation – Fringe frequency

case 3: bad coherence and complex shape





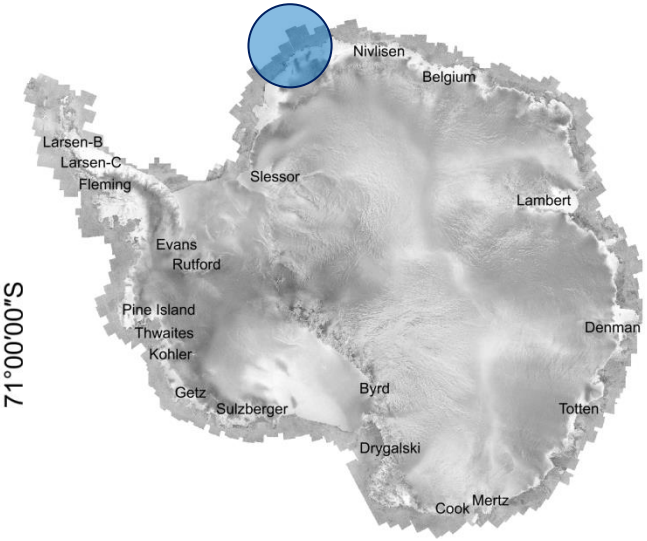
ERS-1/2 acquisitions information:

Track 002A
Master: 1996-02-19
Slave: 1996-02-20

Gradients amplitude 4-6 [cm/km]

AIS_cci GLL generation – Fringe frequency

case 3: bad coherence and complex shape



ERS-1/2 acquisitions information:

Track 002A
Master: 1996-02-19
Slave: 1996-02-20

Gradients amplitude 4-6 [cm/km]

Conclusions

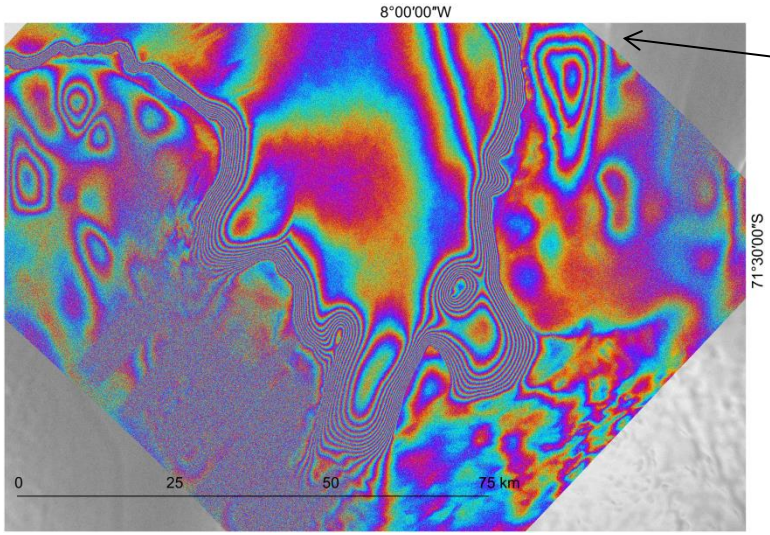
- With Sentinel-1A and TerraSAR-X (repeat cycles 12 & 11 days) the coherence is preserved for slow moving glaciers.
- Sentinel-1A/B constellation (repeat cycle 6 days) shows a considerable improved coherence which extends GLL derivation also for fast moving glaciers → more data needed.
- Accurate and current DEMs (e.g TanDEM-X) can reduce the geolocation error of InSAR processing.
- AIS_cci GLL products are annotated with metadata which allows more precise comparisons and interpretations.
- AIS_cci GLL products are available on ENVEO's cryoportal (http://cryoportal.enveo.at).
- Automatically mapping the GLL through the fringe frequency method is promising but currently limited to highly coherent InSAR pairs. Tuning parameters for various ice streams and ice shelves needed.

Thanking you

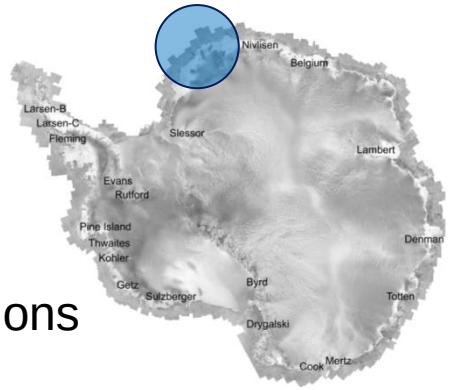
The research leading to these results has received funding from the European Space Agency within the framework of Antarctic Ice Sheet climate change initiative

http://esa-icesheets-antarctica-cci.org/

AIS_cci GLL generation – Fringe frequency

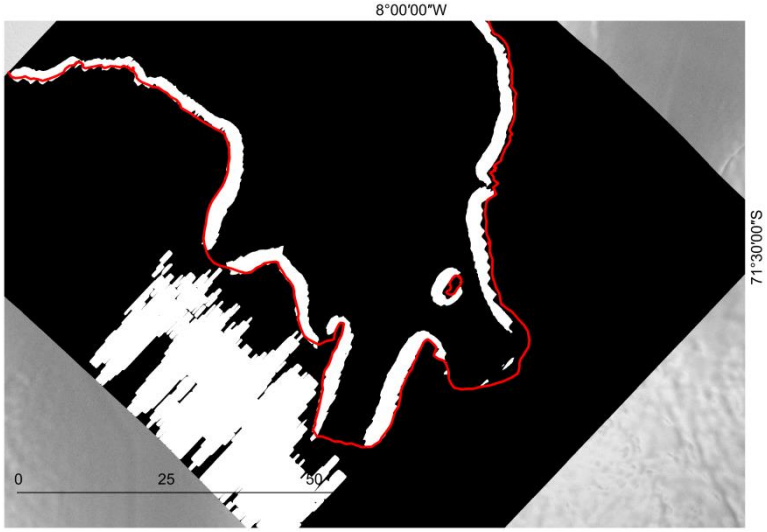


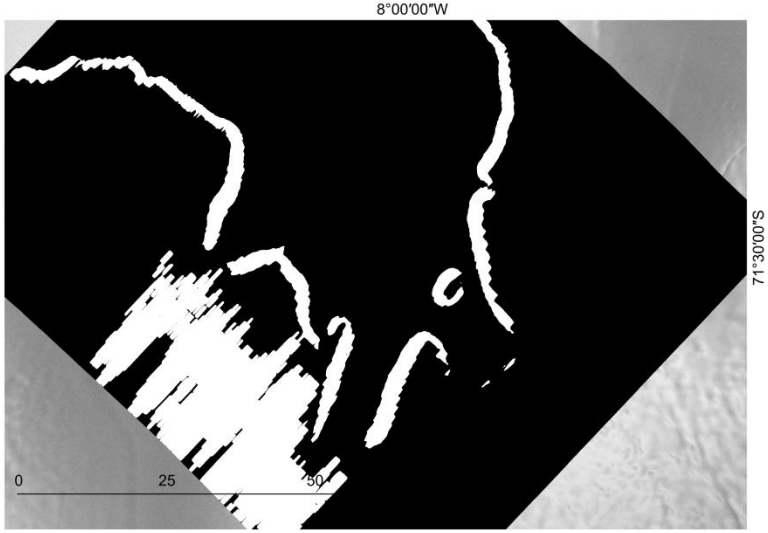
Ekstroemisen Glacier



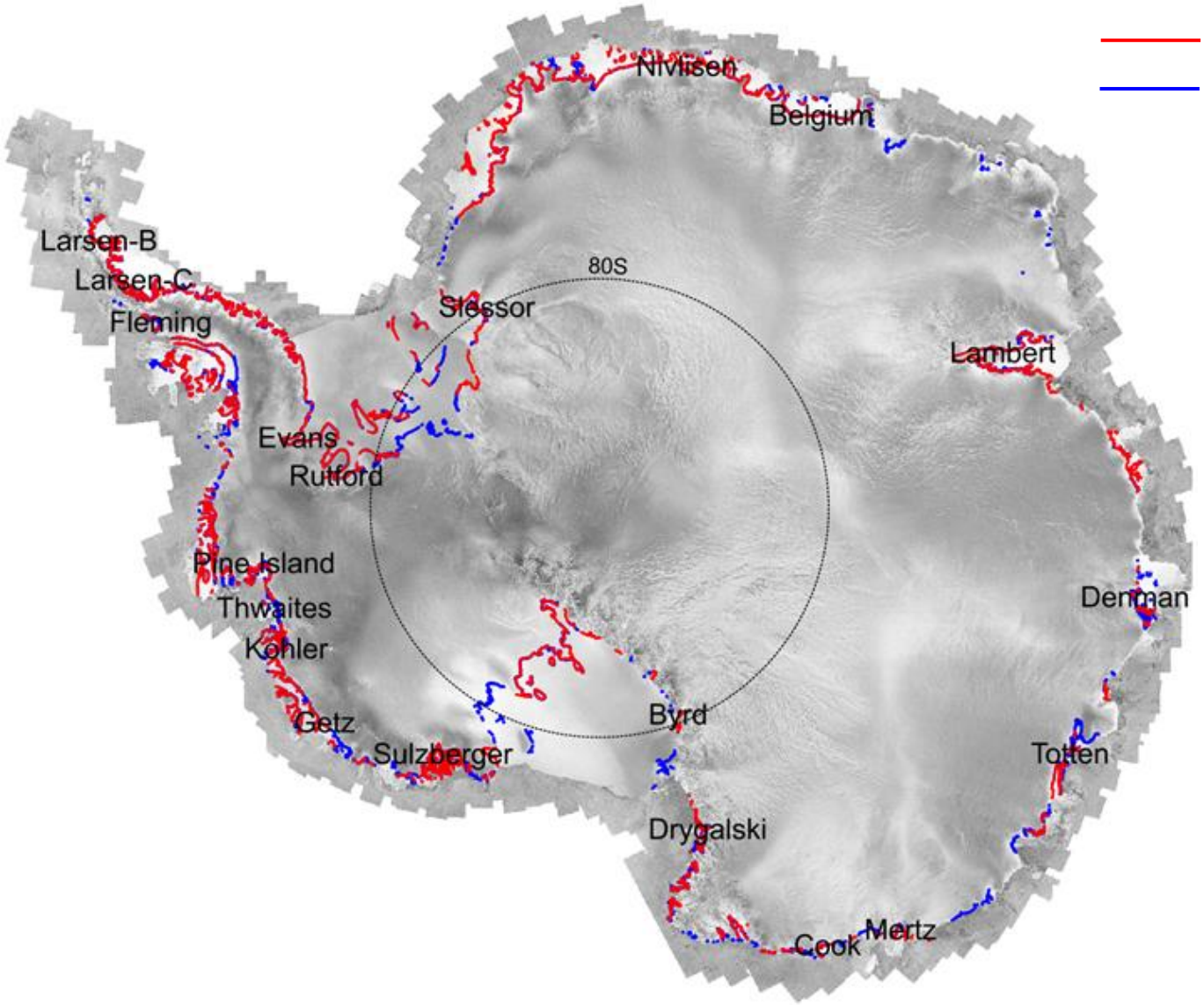
ERS-1/2 acquisitions information:

Track 002A
Master: 1996-02-19
Slave: 1996-02-20

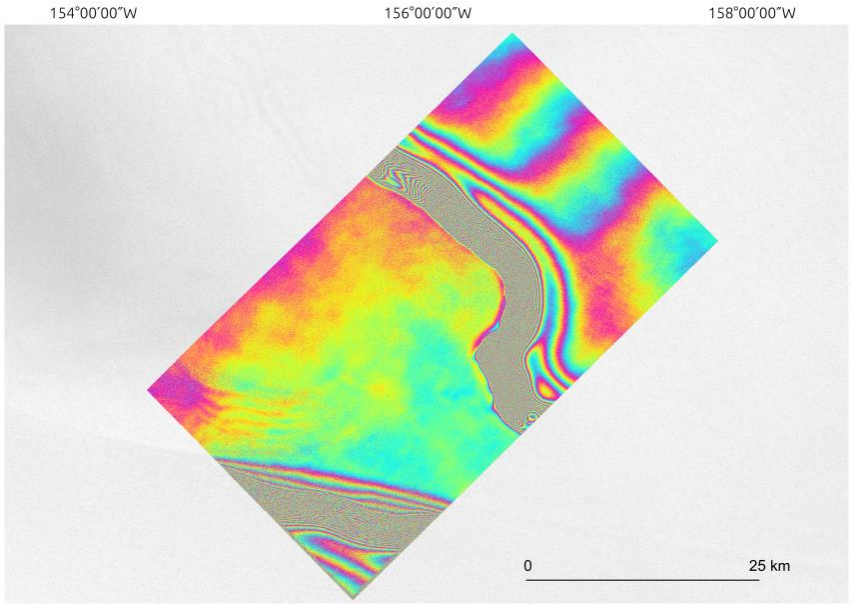




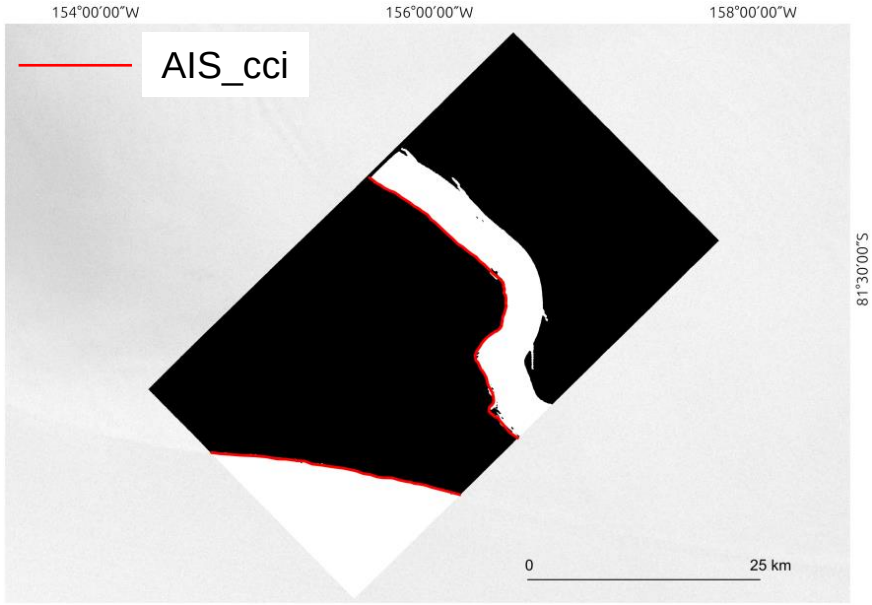
AIS_cci GLL product generation - status May 2017



Fringe frequency – Ross Ice Shelf



Double difference interferogram



Gradients amplitude 6 [cm/km]

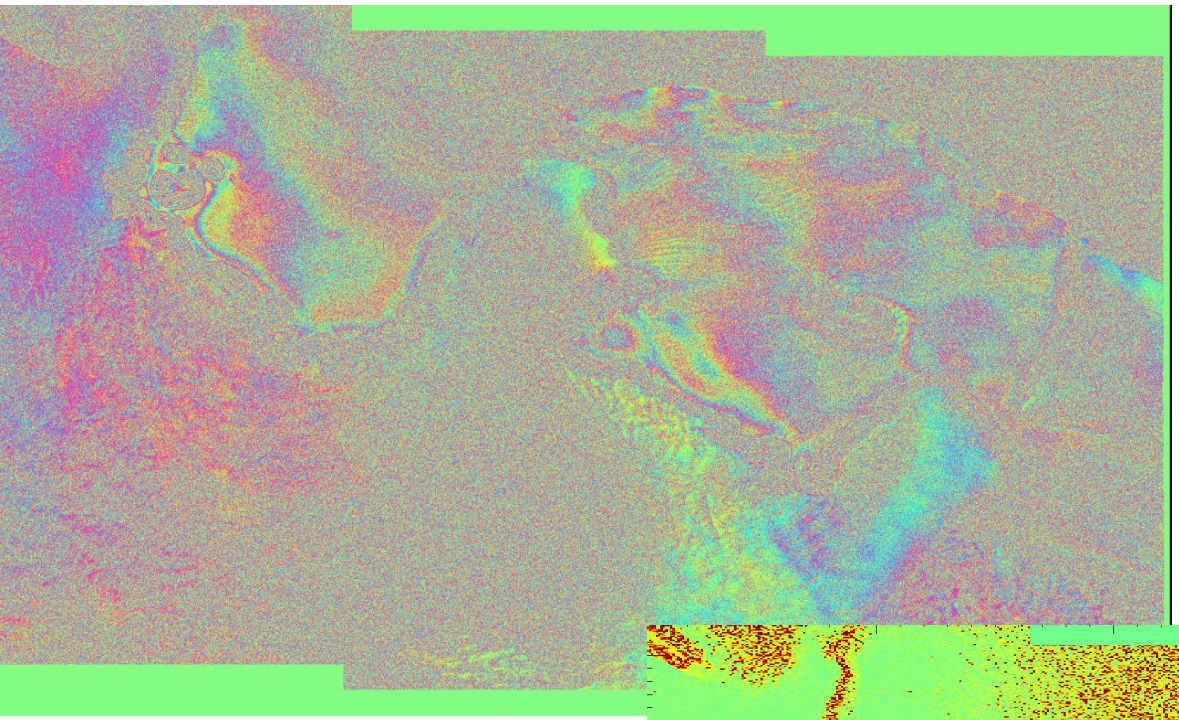
TerraSAR-X acquisition dates:

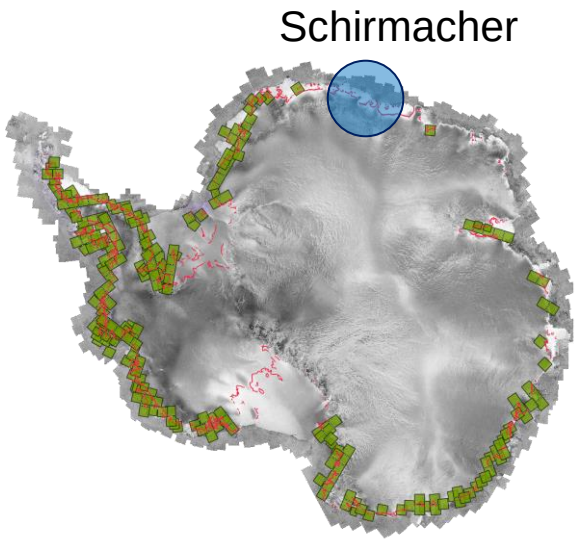
2017.02.20
Master scene **2017.03.03**
2017.03.14

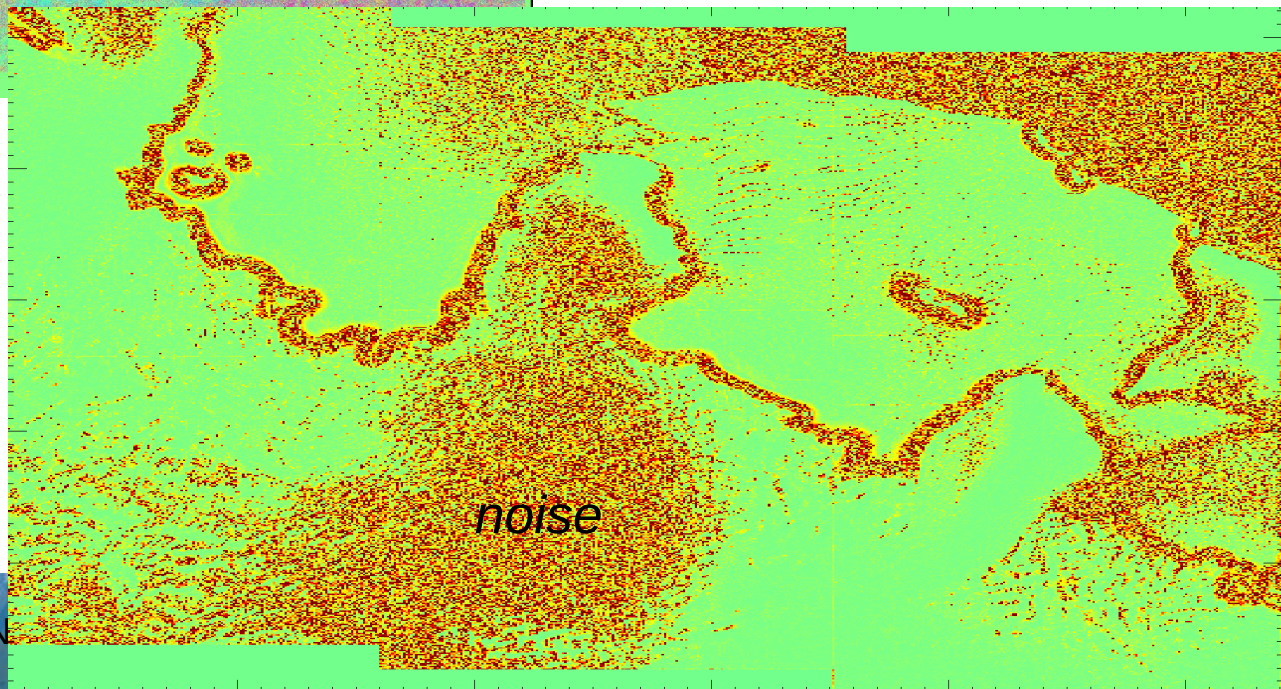
Rel. Orb: 114
Stripmap
Descending orbit
Left looking

AIS_cci_GLL

Algorithm development – preliminary result





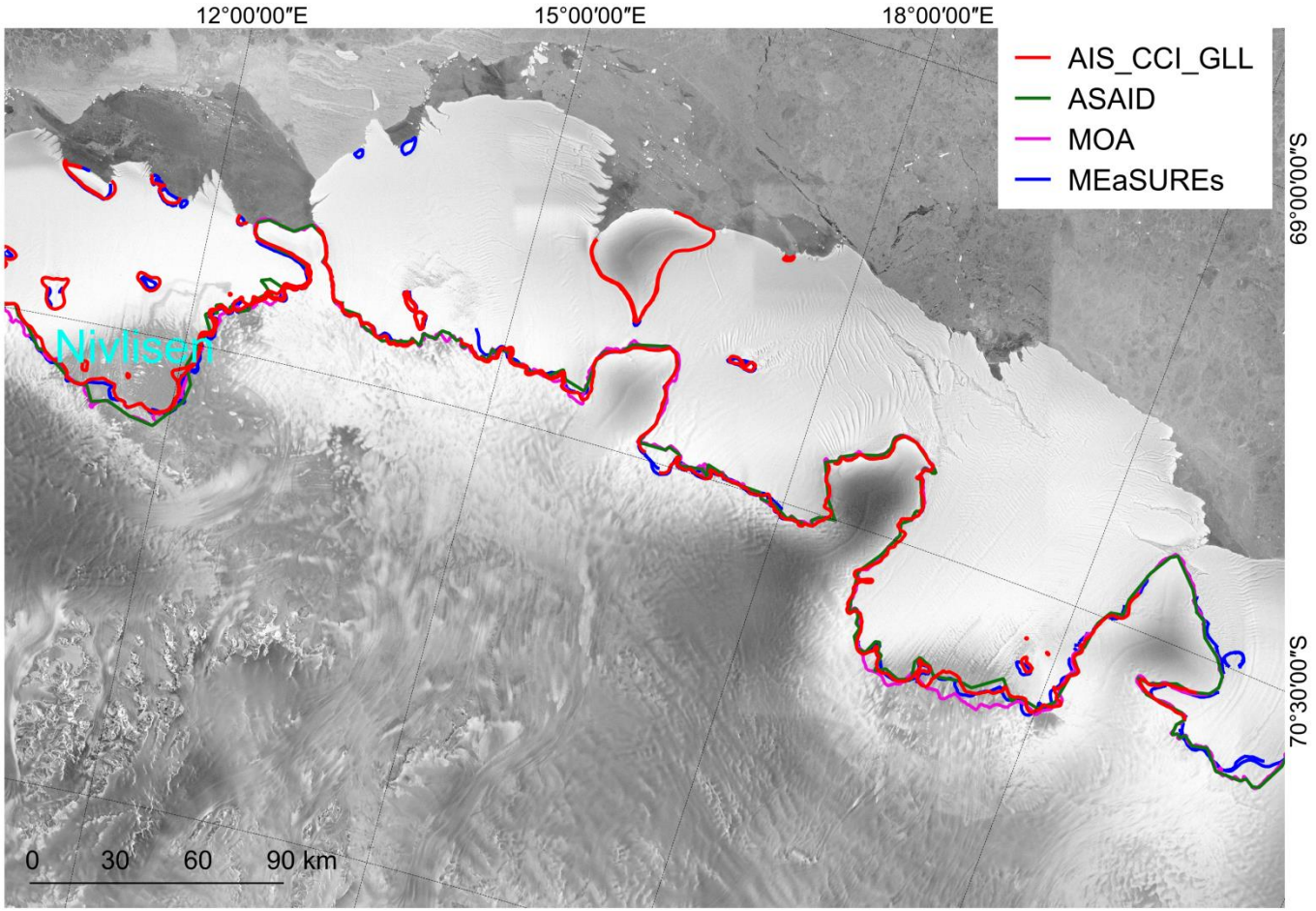


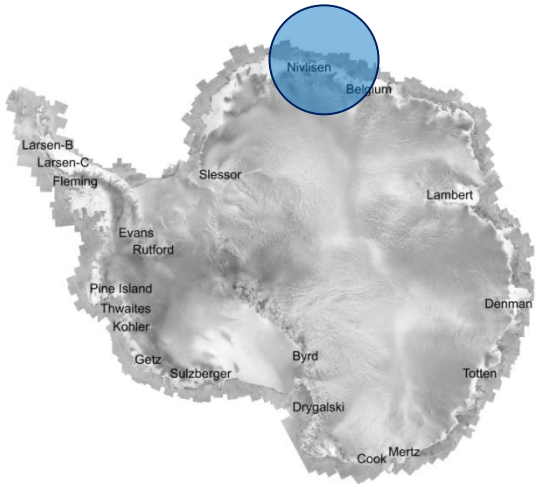
Sentinel – 1A
Relorb: 038
Pass: DES
Lookdir: RIGHT
Date1: 2015-05-25
Date2: 2015-06-06
Date3: 2015-06-18

FRIN

GLL Product Validation and inter-comparison

Schirmacher

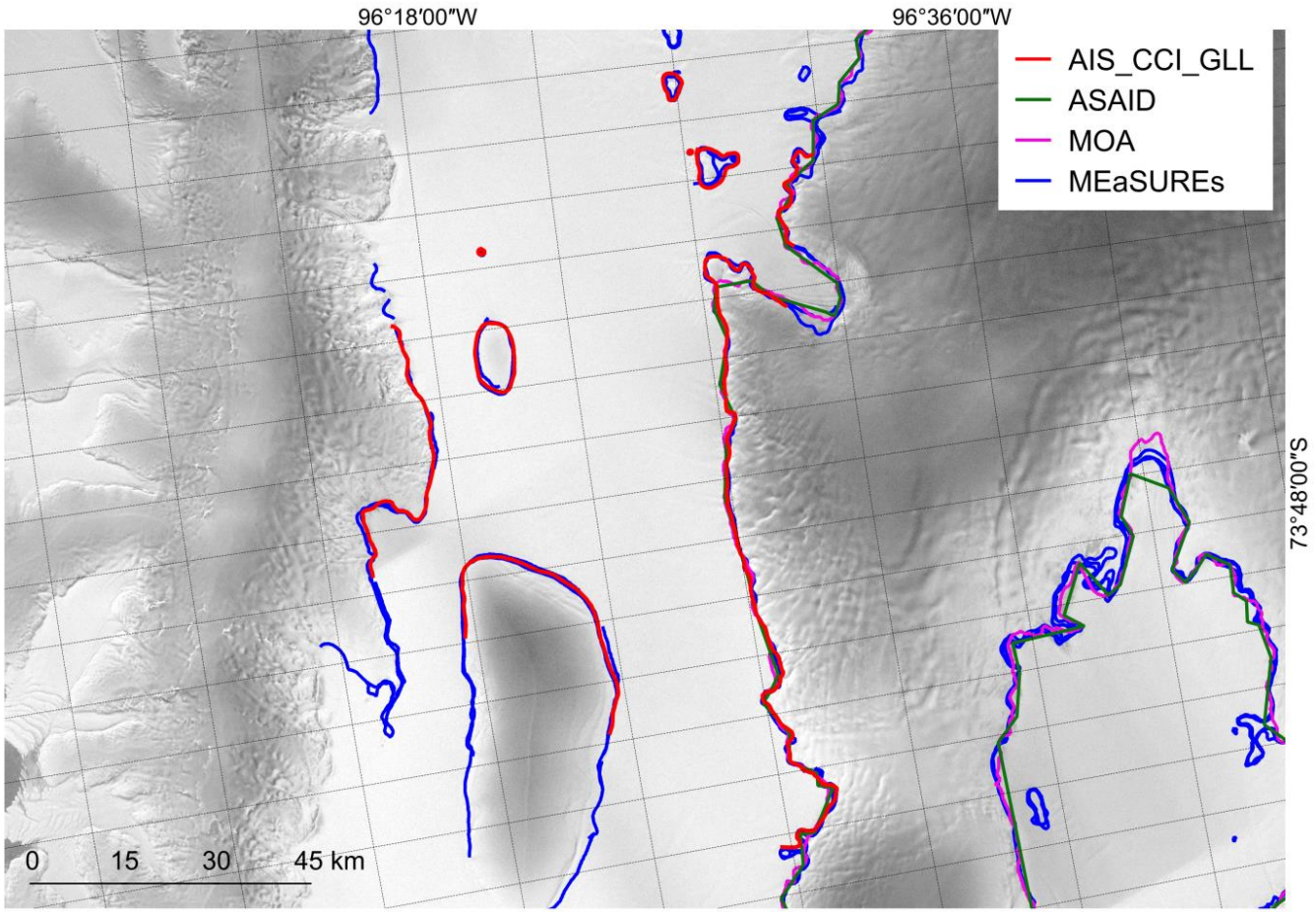


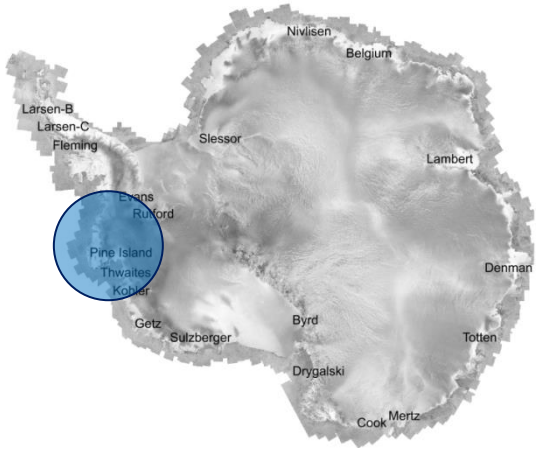


Good agreement

GLL Product Validation and inter-comparison

Pine Island Glacier (PIG)

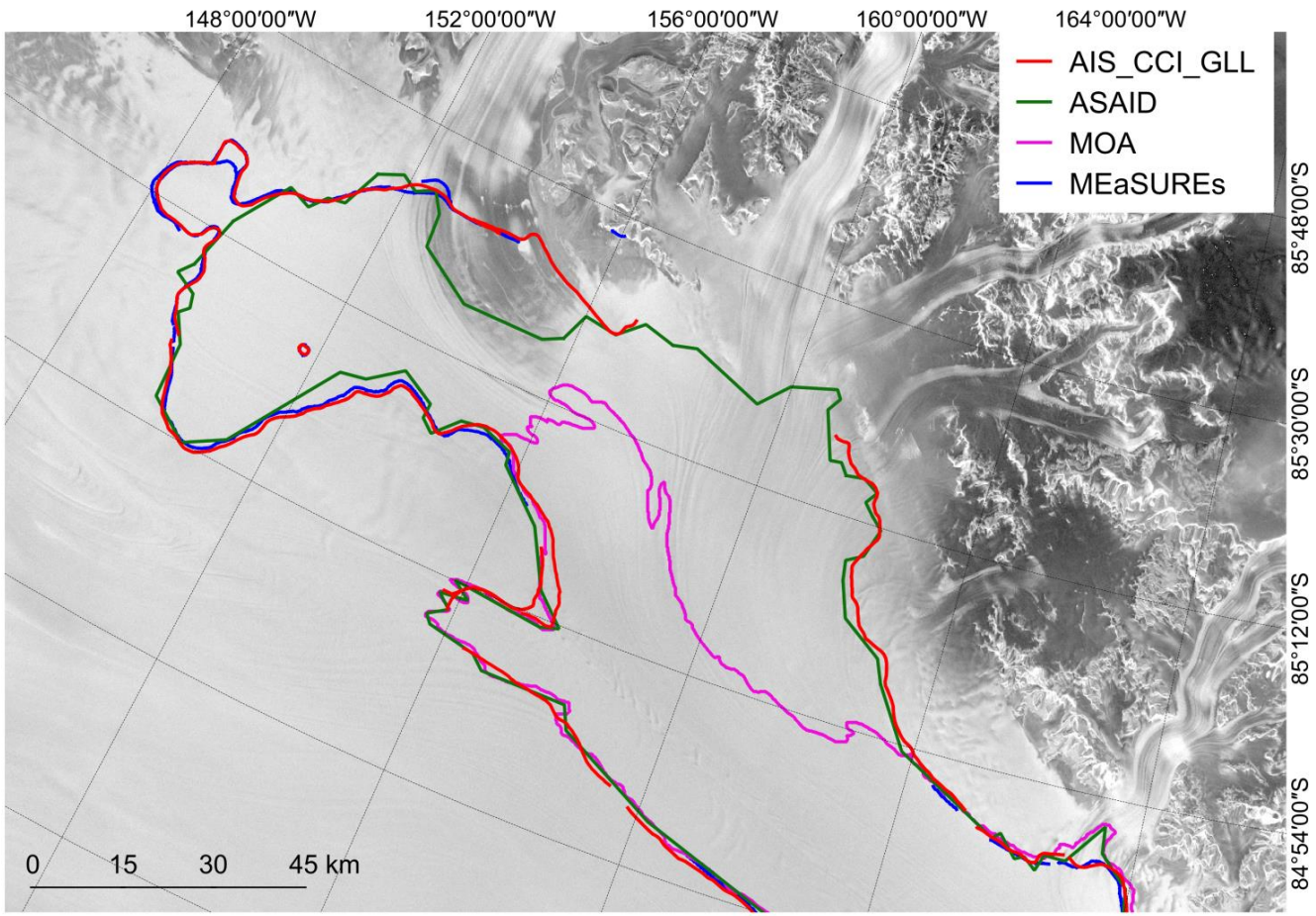


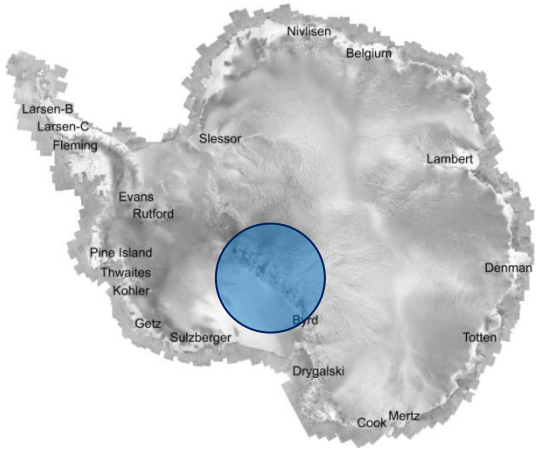


Good agreement

GLL Product Validation and inter-comparison

Transantarctic Mountains (TAM)





less agreement!